Situation Adaptation:

Information Acquisition, Human Behavior and its Determining Abilities

Inauguraldissertation

zur Erlangung des akademischen Grades

eines Doktors der Sozialwissenschaften

der Universität Mannheim

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Tag der Disputation: 16.04.2008

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- Abbreviations –

B	Processing speed
BIS	Berlin Intelligence Structure Model
BIS-4	Berlin Intelligence Structure Test Version 4
CV1	Aggregated control variable 1
CV2	Aggregated control variable 2
DAG	Average difference between the average duration of a gaze on an anchor and on an object
DAG-T1 – DAG-T4	Average difference between the average duration of a gaze on an anchor and on an object in Task 1 – Task 4
df	Degrees of freedom
df_e	Degrees of freedom of the error
df_s	Degrees of freedom of the source
DG	Average duration of a gaze
DG-T1 – DG-T4	Average duration of a gaze conducted in Task 1 – Task 4
DGO	Average duration of a gaze on a specific object
DGO-T1 – DGO-T4	Average duration of a gaze on a specific object in Task 1 – Task 4
DIG	Average duration of an operation-independent gaze in relation to the average duration of a gaze
DIG-T1 – DIG-T4	Average duration of an operation-independent gaze in relation to the average duration of a gaze in Task 1 – Task 4
DIO	Average duration of a task-irrelevant operation in relation to the average duration of an operation
DIO-T1 – DIO-T4	Average duration of a task-irrelevant operation in relation to the average duration of an operation in Task 1 – Task 4
DO	Average duration of an operation
DO-T1 – DO-T4	Average duration of an operation in Task 1 – Task 4
DPL	Average duration of a plan
DPL-T1 – DPL-T4	Average duration of a plan in Task 1 – Task 4
DRG	Average duration of a task-related gaze in relation to the

	average duration of all gazes
DRG-T1 - DRG-T4	Average duration of a task-related gaze in relation to the average duration of all gazes in Task 1 – Task 4
ε^2	Adjusted partial effect size
EID	Ecological Interface Design
F	Figural abilities
f^2	Partial effect size
G	General intelligence
G-G	Greenhouse-Geisser correction
H-F	Huyn-Feldt correction
H^I_1-H^I_{11}	Hypotheses testing the change of the information acquisition and its interaction with the individual differences
H^B_1-H^B_5	Hypotheses testing the change of the human behavior and its interaction with the individual differences
K	Processing capacity
M	Memory
MLS	Motor Achievement Series / Motorische Leistungsserie
N	Numerical abilities
N	Sample size
NA	Number of actions performed
NA-T1 – NA-T4	Number of actions performed in Task 1 – Task 4
NG	Number of gazes
NG-T1 – NG-T4	Number of gazes conducted in Task 1- Task 4
NIG	Number of operation-independent gazes in relation to the total number of gazes
NIG-T1 – NIG-T4	Number of operation-independent gazes in relation to the total number of gazes in Task 1 – Task 4
NIO	Total number of task-irrelevant operations in relation to the total number of operations
NIO-T1 – NIO-T4	Total number of task-irrelevant operations in relation to the total number of operations in Task 1 – Task 4

NO	Number of operations in relation to the total duration of all operations
NO-T1 – NO-T4	Number of operations in relation to the total duration of all operations in Task 1 – Task 4
NPL	Number of plans
NPL-T1 – NPL-T4	Number of plans in Task 1 – Task 4
NRG	Number of task-related gazes in relation to the total number of gazes
NRG-T1 – NRG-T4	Number of task-related gazes in relation to the total number of gazes in Task 1- Task 4
NST	Number of strategic changes
NST-T1 – NST-T4	Number of strategic changes in Task 1 – Task 4
OR	Object relevance
OR-T1 – OR-T4	Object relevance in Task 1 – Task 4
PR	Precision of arm-hand movements
RPD	Recognition-Primed Decision Model
SDG	Average difference between start dates of gazes and related operations
SDG-T1 – SDG-T4	Average difference between start dates of gazes and related operations in Task 1 – Task 4
SRK	Skill, Rules, and Knowledge Model
ST	Steadiness
TP	Tapping/speed of wrist-finger movements
V	Verbal abilities
VE	Velocity of arm-hand movements

INTRODUCTION

1. Motivation: Assistive Technologies

It is well known that the total share of elderly people is steadily increasing, in parallel with the number of citizens with disabilities (see Figure 1). According to the 9th book of the German "Sozialgesetz" (§2, Abs. 1, Sozialgesetzbuch IX), a human-being is considered having a disability, when his/her corporal functions, his/her intellectual abilities, or his/her mental health are atypical for the average age group for a period of longer than six months. Further, this deviation from average must affect the person's participation in life in order to be considered a disability.

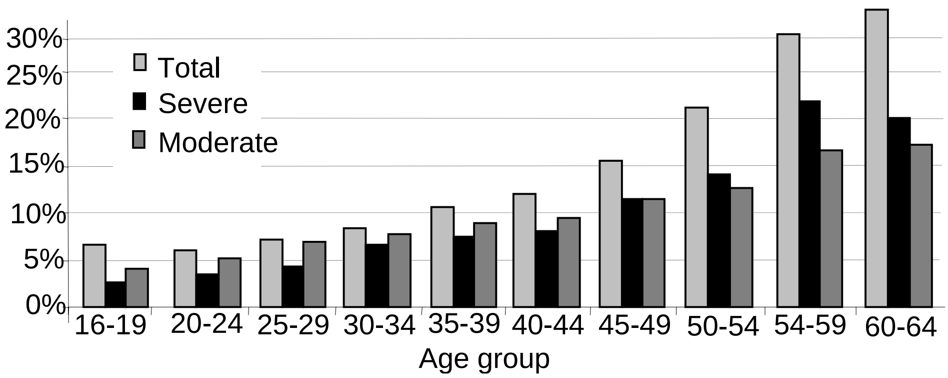

Figure 1. Statistics of the total percentage of disabled people as well as the percentage of severely and moderately disabled citizens from the disabled population in the European Union (adapted from EuropeanCommunities, 2001).

Devices for assisting and supporting disabled people, e.g., wheelchairs, were developed in order to enhance their quality of life, to simplify everyday issues, and especially to enable them to live a – as far as possible – normal and independent life. With the number of elderly and/or disabled people, the number of citizens requiring a wheelchair rises (Forbes, Hayward, & Agwani, 1993), as the dependency on a wheelchair is highly related to age (Zagler, n.d.).

The first proofs for the existence of a wheelchair demonstrate that such an assistive device has already been used around 1300 B.C. in China. A wheelchair which could be controlled by its user was developed by the paraplegic Stephan Farfler in 1966 (see Figure 2).

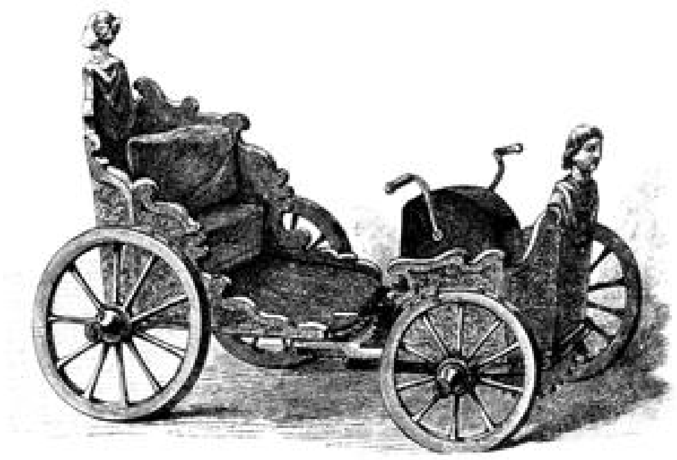

Figure 2. Wheelchair developed by Stephan Farfler in 1655 (derived from Wikipedia, n.d.).

Currently available mobility devices imply serious drawbacks (see e.g., Bailey & DeFelice, 1991; Bateni & Maki, 2005; Chase & Bailey, 1990; Fehr, Langbein, & Skaar, 2000; Maki, Holliday, & Topper, 1994; Mann, Granger, Hurren, Tomita, & Charvat, 1995a, 1995b; Tinetti, Speechley, & Ginter, 1988; Wright & Kemp, 1992). Case studies (see e.g., Bailey et al. or Chase et al.) report of individuals with high-level spinal cord injuries, with multiple sclerosis, or brain injuries who have spent months, even years, learning to control a powered wheelchair, sometimes even unsuccessfully. Fehr et al. support these case studies with their results when questioning clinicians about the difficulties of their patients with conventional powered wheelchair control:

- 9-10% of the clinicians' patients receiving training to control a powered wheelchair stated that it is extremely difficult or even impossible to use the assistive device in their everyday life.
- Clinicians indicated that about 40% of the patients receiving the training hardly accomplish special steering and maneuvering tasks.
- Nearly as many patients as receiving powered wheelchair training cannot use a powered wheelchair due to lacking motor skills, strength or visual acuity.

Summarizing the various research results, the control of assistive devices requires lengthy and tedious training phases and imposes a high cognitive, memory, and attentional workload on their users. Hence, the lack of mobility leads - together with the burdens of controlling the mobility devices - to a substantial physical and cognitive workload on the people in need.

These drawbacks are even increased when analyzing the assistive technologies for people with severe impairments. Depending on the type and degree of disability, the standard joystick can hardly be controlled, so that specialty controls have been developed (such as the sip-puff device or the chin control, see Figure 3), which even multiply the discussed drawbacks.

Figure 3. Specialty controls (left: sip-puff device; right: chin control).

Specialty controls only allow for a limited set of input commands, so that even simple behavior (such as driving around a table) is tedious to accomplish and can only be achieved by giving many input commands (first, the command must be given to drive straight ahead, then the wheelchair must be stopped, the mode must be changed to enable the wheelchair to change its direction, then the command must be given to change the direction in the desired way, the wheelchair must be stopped, the mode must be changed to be able to drive straight ahead again, etc.). Symptoms of fatigue, high cognitive load, and long learning/skill acquisition processes of controlling such a wheelchair result to an even greater degree compared to the traditional joystick control. These problems are further magnified, as 95% of the people in need use joysticks, sip-and-puff, head- or chin-controls to steer their powered wheelchair, so that the full spectrum of available specialty controls is not taken advantage of (Fehr, Langbein, & Skaar, 2000). Hence, the opportunities for optimally supporting the people with various types and degrees of impairments are not exploited sufficiently (Shaw, Flascher, & Kadar, 1995). The serious drawbacks, which have been described before, are the result. Despite, it is to be considered that for some groups of disabled people, who are incapable of controlling a powered wheelchair due to e.g., lacking strength or insufficient motor skills, no assistive technologies are available.

These problems with conventional powered wheelchair control will gain importance in the up-coming years due to the demographic changes, which especially highly developed countries face, and the, herewith, increasing share of the people in need. This demonstrates the pressing need to develop more naturally usable wheelchair control better supporting all users in need.

This complex of problems with current wheelchair control has been realized and tackled by research groups in the field of computer engineering. Two areas of research can be distinguished (for a more detailed review, see Bartolein, Wagner, Jipp, & Badreddin, 2007 or Jipp, Bartolein, & Badreddin, 2007):

First, methods, which were developed in the field of Mobile Robotics were adapted and implemented on (semi-) autonomous wheelchairs. For instance, Bell, Borenstein, Levine, Koren, and Yaros (1994) realized a collision avoidance behavior on a powered wheelchair. Other researchers eased navigation by implementing sets of basic behaviors such as wall following or door passage (see e.g., Lankenau & Röfer, 2000). Further, the behavioral intention of the user has been estimated based on probabilistic methods to reduce the, from the user required command set (see e.g., Demeester, Nuttin, Vanhooydonck, & Van Brussel, 2003). The authors extrapolated the route indicated by the user’s input and compared it with potentially requested routes to given goals in the surrounding.

Second, especially for severely disabled wheelchair users, eye movements have been used to control the device, which can be combined with the above described methods developed in the field of Mobile Robotics and adapted for powered wheelchair control. For example, eye movements have been measured based on EOG (electro-oculographic potential) and used in order to control the wheelchair directly (e.g., looking right is interpreted as driving to the right) by Barea, Boquete, Bergasa, López, and Mazo (2003), or indirectly by selecting icons on a given display (Yanco, 2000). Other researchers implicitly controlled the wheelchair based on an attention histogram of fixations on potential goal positions in the surrounding environment (see e.g., Adachi, Tsunenari, Matsumoto, & Ogasawara, 2004).

These approaches are not optimal regarding their usability and are, thus, not expected to wipe out the above-described drawbacks of traditional wheelchair control. First, the existing implementations of behaviors developed in the field of Mobile Robotics do facilitate navigation, but not in a comprehensive manner. Only special situations are tackled (such as passing through a door). The approaches estimating the intention of the user are only based on low-level information such as past routes, but do not consider the cognitive processes of the user. Making use of additional information in a cognitive model of the user would enable to estimate first the user’s future operation (e.g., watching the news) and second the long-distance goal position of the user (e.g., the television set in the living room while being in the kitchen). Such a prediction would significantly reduce the, from the user required set of input commands. The high number of required input commands is expected to be one reason for the above mentioned drawbacks of traditional wheelchair control. Second, the gaze-based wheelchair control so far does not sufficiently consider physiological/psychological research results. It is, for instance, not taken into account that unintentional eye and/or head movements occur, when e.g., an unexpected sound appears. Besides, the user has to acquire the skill to explicitly control his/her eye movements to e.g., select icons on the display. Hence, existing gaze-based wheelchair control is still unintuitive.

2. Purpose and Definition of Goals

It is the major strategic goal of this work to approach the described serious drawbacks of traditional and assisted electrically powered wheelchair control by providing psychological insights required for developing an assistance system which makes controlling a powered wheelchair more usable. This envisioned system will be controlled with the user’s natural gaze behavior and will further support the disabled person with navigation aids which were developed in the field of Mobile Robotics (such as e.g., collision avoidance, path planning). In the long run, the assistance system should further be able to predict a user's most likely future operation(s), to judge whether this operation will require moving to another goal position and, if yes, to drive the user to that goal position if the user concords. In order to yield such an assistance system, which control does no longer cognitively and physically burden its user as the number of required input commands will be significantly reduced, knowledge about the user's cognitive processes must be acquired and transferred to the design of highly complex systems. More specifically, this work aims at analyzing (1) the way of how information in the environment is processed by an observer, (2) the relationship between the information in the environment and the observer's behavior, (3) the abilities which determine the information acquisition and the human behavior, and (4) the interplay between information acquisition and human behavior changes in environments, which are more or less familiar to the actor, in relation to the abilities determining information acquisition and human behavior.

These cognitive processes (i.e., information acquisition, human behavior) and determining variables (i.e., abilities, familiarity of the situation) give important insights which need to be considered when developing the assistance system due to the following reasons: First, the analysis of the information acquisition in relation to the user's abilities and the familiarity of the situation will provide information on the natural gaze behavior, which must be considered when developing the assistance system, so that controlling the wheelchair does not require the user to adapt the natural gaze behavior to the system. Second, human behavior is considered a function of the structure of the environment and cognitive processing. The importance of both will change depending, amongst others, on the familiarity of a situation: In highly familiar situations, the structure in the environment will play a more important rule (see e.g., Simon, 1969), while in new situations, cognitive processes will be determining human behavior. Hence, in order to be able to predict human behavior in a given situation, a thorough analysis of acquisition of the information available in the environment, its impact on behavior, and the relevance of variables such as abilities and the familiarity of the situation is required.

3. Outline

In order to provide the engineers with the necessary inputs about the cognitive processes of information acquisition and human behavior and its determining variables such as abilities and adaptation of the human being to his/her environment, the following steps have been taken:

First, a theoretical basis is provided. Relevant theories regarding information acquisition are introduced, discussed and put in relationship with each other regarding the variable linking them, which is, the familiarity or the novelty of a situation. Then, theories classifying human behavior are introduced and their relationship with information acquisition discussed, as well as the impact of the novelty of the situation. Based on the cognitive processes underlying the described changes of information acquisition and human behavior in the course of adapting to a new environment and based on research conducted in the field of skill acquisition, abilities are discussed, which are expected to determine information acquisition and human behavior in the course of adaptation.

Second, a study has been conducted to test major assumptions of the derived theoretical advancements. The according method section describes the research questions and the variables of interest, the method applied to calculate the required sample size, the apparatus and material used to collect data, the setting and the course of the study, the characteristics of the participants as well as the analytical strategy used to analyze the data and the derived results.

The final section discusses the results and puts them in relation to the in, the first part derived theoretical advancements. Conclusions are drawn regarding the assistance system to be developed: The behavioral phenomena of natural gaze behavior to be considered by the engineers when developing the assistance system are summarized, as are implications regarding predicting human operations in given environments.

THEORETICAL FOUNDATIONS

4. Introduction

Theories are introduced and discussed classifying and explaining different processes of information acquisition (see Section 5) and human behavior (see Section 6). The different theories are put in relationship with each other, on which basis continui for information acquisition and for human behavior are proposed depending on the familiarity of a situation, as are underlying cognitive processes. The relationship between information acquisition and human behavior is also considered.

Information acquisition is in this context defined as covering information perception, located on the one end of the continuum and deeper processing such as, e.g., problem solving and decision making, located on the other end of the continuum.

Based on the cognitive processes underlying both continui and research conducted in the field of skill acquisition, different abilities influencing which mode of information acquisition/human behavior takes place, are discussed (see Section 7). Skill acquisition has to be distinguished from the situation adaptation of interest here, as skill acquisition does only consider the expertise of a pattern of movements, which is, however, independent from the situation in which behavior takes place. In contrast, the definition of situation adaptation applied in this work covers the adjustment to an unfamiliar environment, in which a new pattern of movement is to be applied.

Last (see Section 8), a summarizing overview is given of how the processing of information in the environment and the behavior changes with the familiarity of a situation, what the relationship is between the information acquisition and behavior, as well as what variables determine the change of information acquisition and behavior.

5. Information Acquisition: Information Perception and Processing

In the following, theories and models are introduced, which give insights into different modes of information acquisition, which can, on the one end of a continuum be described as perception and on the other end as cognitively demanding information processing. This continuum, as are the processes underlying the different, artificially separated phases of information acquisition, is thoroughly described in Section 5.7. As a variable mediating which mode is applied in a given situation, an adaptation process of the observer to his/her environment is discussed. The Sections 5.1 - 5.6 have been sorted in increasing order according to their location on the expected continuum of information acquisition.

5.1. Direct Perception

The origin of direct perception and ecological psychology is the gestalt theory. According to Koffka (1935), each object specifies what can be done with it, i.e., its *demand character*. Kurt Lewin used the term *Aufforderungscharakter*, which was translated as *invitation character* by Brown (1927) and *valence* by Adams (1931) (for a review regarding the translation issue, see Marrow, 1969). A valence can be interpreted as a vector, which can make the observer approach the object or can push him/her away. It is based on experience and the observer's current needs. The major difference to the concept *demand character* is that the valence changes depending on the needs of the observer. The demand character is always available to be perceived.

Gibson's ecological theory of direct perception (1979), which is related to the concept of the demand character and which establishes a basis for the described continuum of information acquisition, is outlined in the following. Then, relevant, further developments are laid out, as is their theoretical relevance in the continuum of information acquisition.

5.1.1. Ecological Theory of Direct Perception

Human beings do not sense various levels of atoms or particles; instead they perceive mediums, surfaces, and substances, and especially, which actions the combination of these features offers. These action possibilities available in the environment are termed *affordances* and own the following properties (Gibson, 1979):

- Affordances depend on the observer, as the relevant ecosystem consists not only of the objective environment but also of the actor.
- The existence of affordances is independent from the actor's capabilities to perceive them.

- Affordances are independent from the observer's needs, wishes, or goals.

Affordances are objective, because they do e.g., not depend on the actor's goals, but subjective, because they depend on the action capabilities of the observer (Gibson, 1979). For example, a heavy object does not comprise the affordance "lifting" due to lacking power of the actor.

Affordances are sensed by *direct perception* meaning that affordances are received without any further information processing (Gibson, 1979). Each affordance is uniquely specified by invariant information in the optic array, although the affordance is independent from this information. The optic array consists of the light rays which arrive at the human eye and which are distracted by the various surfaces they hit on their way.

Generally speaking, direct perception of affordances is possible, (1) when there is an affordance available, and (2) when there is invariant information in the optic array specifying this affordance. However, the experience of the observer and his/her culture might influence the individual's ability to directly perceive the affordance in question. Hence, the observer might be required to learn to discriminate patterns in order to be capable of perceiving the affordance by adequate sensory information.

5.1.2. Further Developments and Application in the Field of Human-Computer Interaction

Gibson's (1979) direct perception was introduced to the human-computer interface research community by Norman (1988) and has, since then, attracted much attention, as the concept of affordances allows analyzing the interaction between the environment (i.e., the computer program) and the actor (i.e., the user). However, Norman defines affordances slightly different as does Gibson, resulting in confusions about the original concept and various definitions applied today (see e.g., Chemero, 2003; Turvey, 1992). According to Norman affordances are "perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used" (p. 9). The most fundamental difference to Gibson's definition is, that according to Norman affordances are both the action possibility and the way it is made visible to the actor/observer. Gibson, however, strictly separates between the affordance and the perceptual information specifying it. Another crucial difference is that Norman argues that affordances result from the mental interpretation of objects, based on knowledge and experience, whereas Gibson's affordance opposes that information processing is required to perceive affordances. In his later publications, Norman (1999) re-defined affordances and used the term *perceived affordances* in order to separate his concept from the Gibsonian term.

Research in the field of human-computer interaction related to Gibson's concept of affordances (1979) can be sorted basically in two categories (McGrenere & Ho, 2000): affordances in software applications (see e.g., Baerentsen, 2000; Smets, Overbeeke, & Gaver, 1994) and affordances of physical objects (see e.g., Zhai, Milgram, & Buxton, 1996). In the field of software applications, Gaver (1991) extended Gibson's definition of affordances and distinguished false, perceptible, and hidden affordances, as well as correct rejections, based on the availability of perceptual information and on the existence of the affordances themselves (see Table 1). If there is information available for an existing affordance, the affordance is *perceptible*. If there is no information available for an existing affordance, the affordance is *hidden* and must be inferred from other evidence (i.e., learnt). If, however, perceptual information points to a non-existing affordance, this is termed a *false affordance*, although it is the information which is wrong and not the affordance. Last, when no information about a non-existing affordance is available, it is a *correct rejection*. Gaver further enhances the original concept in respect to complex and sequential affordances, as acting on a perceptible affordance results in new/updated information indicating new existing affordances.

Table 1

Types of Affordances According to Gaver (1991)

		Affordances	
		Non-existent	Existent
Perceptual Information	Available	False Affordance	Perceptible Affordance
	Not available	Correct Rejection	Hidden Affordance

5.1.3. Theoretical Relevance of Direct Perception in the Context of Information Acquisition

Gibson's (1979) main contribution is certainly the development of the concept of affordances and the theory that higher order properties of the environment can be perceived directly based on the invariant information in the ambient optic array without any further information processing. If an individual is unable to perceive this invariant information, a learning mechanism has been proposed by Gibson, which is based on the discrimination of patterns in the optic array. This type of adaptation process is facilitated by executing different types of activities, which Gibson distinguishes and which are described in Section 6.1.

Although Gibson (1979) has introduced this adaptation process, he did neither sufficiently take into account individual differences in information perception and processing (see Section 7.1) nor did he consider that the information in the optic array might not be fully available or ambiguous (see Gaver, 1991 or Section 5.1). If either the cognitive abilities of the observer are not available to a sufficient degree or the information in the optic array is disrupt or too complex, higher level information processing will be required in order to be able to – at a later stage of situation adaptation – directly perceive the affordances. Hence, an, initially hidden affordance gets perceptible. However, this learning or adaptation process to the situation is only possible, if, again, the cognitive abilities of the observer are sufficiently developed and the information is consistent during the adaptation process (see Section 7.2).

More specifically, it is postulated (1) that direct perception of affordances in an unknown environment is possible, if the complexity of the environment is small, (2) that, if the complexity of the environment does not allow for initial direct perception, higher cognitive processes are required to make initially hidden affordances directly perceptible (see Gaver, 1991), and (3) that direct perception is not possible, if the information in the environment is inconsistent or too complex to be adapted to completely by an observer with a given degree of cognitive abilities. If these presumptions are given, direct perception, as proposed by Gibson (1979) is expected to be the final stage of the situation adaptation process.

5.2. *Probabilistic Perception and Thinking as Ratiomorphic Processes*

The assumption that information in the environment is not always fully available is based on Brunswik's theory of probabilistic functionalism (1957). Brunswik's research mainly focused on perception; however in the first and last years of his scientific career, he has also shown interest for analytical cognition and subsumed perception and thinking under the term *cognition* or *ratiomorphic processes* (see e.g., Brunswik, 1956). His theory is introduced in the following, as is a comparison to Gibson's (1979) approach to direct perception (see Section 5.1). Last, the role of probabilistic perception and thinking in relation to information acquisition is introduced.

5.2.1. *Probabilistic Perception*

Brunswik (1937) distinguished between distal and proximal variables: *Proximal variables* represent the sensory input the organism receives from the environment; whereas *distal variables* define descriptions of the surrounding environment. The proximal variables are probabilistic cues for the distal variable. Hence, direct perception of the distal variable as proposed by Gibson (1979) is not designated in Brunswik's theory (1937). The mathematical principles of communication (Shannon & Weaver, 1949) are used by Brunswik (1955) in order to explain his probabilistic approach: The perceptual cues can be considered as signals in coded messages, which are communicated in overloaded channels. However, messages, transported in overloaded channels, cannot be decoded without error or at least uncertainty about the true message. The result is equivocation, which makes a probabilistic approach necessary.

The relationship between the distal and proximal variables can be described for an objective environment and for the environment as perceived by an observer. Both relationships can be described by the lens model (Brunswik, 1955), which is a symmetrical framework (see Figure 4) and is based on the principle of parallel concepts (see e.g., Hammond, Stewart, Brehmer, & Steinmann, 1975). The lens model and its underlying formalisms allow uncovering the complexity of the following relationships between the objective and observer-dependent environment

(Cooksey, 2001): It captures (1) *achievement* demonstrating the adjustment of the organism to its environment, (2) *vicarious mediation* describing the relationship of proximal cues to distal variables/events, and (3) *vicarious functioning* referring to the relationship of proximal cues to central processing events in the organism. In the original version of the lens model, Brunswik (1955) included a feedback loop, which has been ignored in earlier research and only recently been re-considered (see e.g., Brehmer, 1990).

The formalism underlying the lens model, as proposed by Brunswik (1955), is the multiple regression, as its properties are similar to those of perception: Both use multiple, correlated proximal variables with limited ecological validity and a mathematical measurement of the distal variables' congruence. The cues need to be accumulated and combined in order to derive a value on the distal variable. This cognitive activity underlying perception is termed *quasi-rational* by Brunswik (1956). However, in Brunswik's work (1955, 1956) there is no statement suggesting that multiple regression is a duplication of cognitive activity (Hammond & Stewart, 2001), although Brunswik (1934b) proposed that methods are not independent from theory.

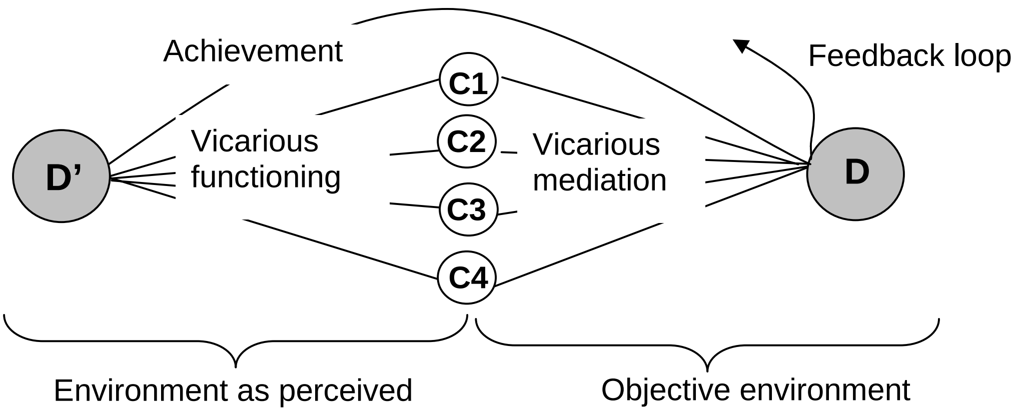

Figure 4. Lens model according to Brunswik (1955) showing the relationship between proximal cues (C1 – C4), a distal event (D) and the perceived distal event (D').

Although the lens model was originally introduced to analyze perception, already Brunswik has argued (1955) that analyzing the relationship between distal events and proximal cues can be applied in various fields of psychology such as molar behaviorism (Tolman, 1932), dynamic personality theory (Murray, 1940), learning theory (Hull, 1943), factor analysis and mental testing (Spearman, 1904; and Thurstone, 1938), cybernetics (Wiener, 1948) and communication theory (Shannon, 1948).

Especially in the field of judgment and decision making, the lens model framework has let to substantial and seminal contributions to understanding the influence of the environment on human judgment activities (Brehmer & Joyce, 1988). Based on its extensions (e.g., Castellan, 1972; Cooksey, 1996; Hammond, Stewart, Brehmer, & Steinmann, 1975; Hursch, Hammond, & Hursch, 1964; Stenson, 1974; Stewart, 1976; Tucker, 1964), it is nowadays a common framework to quantitatively describe human judgment behavior (Brehmer & Joyce, 1988; Brunswik, 1955; Cooksey, 1996; Hammond, Stewart, Brehmer, & Steinmann, 1975).

For example, by identifying characteristics of successful performance on a judgment task based on a lens model approach, judgment feedback has shown to be highly effective (Balzer, Doherty, & O'Connor, 1989; Balzer, Hammer, Summer, Birchenough, Martens, & Raymark, 1994; Balzer, Sulsky, Hammer, & Summer, 1992). Further, Bisantz, Kirlik, Gay, Phipps, Walker, and Fisk (2000) have demonstrated that the lens model is applicable in the context of decision making in complex human-machine systems and that it can be extended to cover dynamic aspects of decision making by using individual, time-dependent environmental models for each participant. The judgment task, the eight participants had to execute, was to identify an aircraft as either hostile or friendly based on sources of information (cues) such as speed or altitude. A lens model analysis was calculated and quantitative measurements for the participant control of about $R_S = .77$ (i.e., how well can human judgments be predicted with a linear model of the cues), for the environmental predictability of about $R_E = .80$ (i.e., how well can the distal event be predicted with a linear model of the sources of information), for the achievement of about $r_a = .95$ (i.e., the correlation between the participants' judgments and the actual values of the environmental criterion to be judged), for the linear knowledge of about G = 1.00 (i.e., how well do the predictions of the model of the human judge match the predictions of the model of the environment), and for the unmodeled knowledge of about C = 0.85 (i.e., the measurement of the components that are shared by both models but are not captured in the linear regression model) were derived. Besides, an error analysis revealed a very good fit between the participants' and the environmental predictions (*r* = .95) for the error cases. Both analyses demonstrate that performance differences were not based on the quality of the models themselves but on the participants' abilities to execute consistent judgments.

5.2.2. The Environment as a Causal Texture

The research of Tolman (1932) and Brunswik (1934b) reflects parallels which were more thoroughly discussed in their joint paper from 1935:

Tolman (1932) studied the relationship of means-objects and ends in the learning activities of rats and argued that the environment is a causal texture, in which different events depend on each other. Hence, organisms in this environment learn that one event is representative of another one and start reacting on this local representative. According to Tolman, the causal texture is equivocal, as the same local representatives are also causally connected to other events, however, with differing probabilities.

Brunswik's (1934b) research on the relationship of stimulus cues (or signs) and distal objects in human perception yields similar insights: Tolman's equivocality (1932) equals Brunswik's probabilism, Tolman's causal texture and relationship between local representatives and events is similar to Brunswik's concept of proximal and distal events.

Combining these theories, results in an extension to another level: Proximal cues (e.g., light-wave bundles) must be selected as the most probable local representative for an object characteristic. This characteristic must in a second step be selected as the most probable local representative for the final goal of the individual. In order to enable this loop to fire, the organism needs experience to perceive both representatives, which, when put in a row, point to some distal event/goal.

Hence, experience allows the organism to forming hypotheses concerning the causal constraints involved in the environment and to judging on the probability to reach the final goal. The relevant hypotheses get activated based on the influence of the need-goal side (e.g., hunger), and the sense organs open. If proximal cues from a possible available means-object are available in the environment, the means-objects turn into signs and are perceived as means to reach the goal. Action is initiated to achieve the goal. This chain of means-objects can be extended arbitrarily.

Each means-object has three characteristics:

- The discriminanda of an object describe its properties (e.g., shape, color, size) which enable to discriminate it from other objects.
- The manipulanda of an object are the actions which are enabled by the object. They are the object's "grasp-ableness", "pick-up-ableness", etc.
- The utilitanda of an object point to the goals, which can be solved by the means of it.

The relationships between the discriminanda, manipulanda, and utilitanda of various objects are equivocal, as are the relationships between goals and means-objects as well as between means-objects and proximal cues for means-objects. In order to simplify the issue of equivocality, Tolman and Brunswik (1935) have defined four types of relationships between means-objects and goals:

- Choosing the good means-object results most likely in a positive goal.
- Applying the ambivalent means-object results only with a relatively high probability in a positive goal. This probability is greater than the one of a negative outcome when using the ambivalent means-object.
- Using the indifferent means-object leads with a very little probability either to a negative or a positive goal.
- Choosing the bad means-object leads with a high probability to a negative goal and with a very little probability to the desired positive outcome.

Tolman and Brunswik further specify four main types of cues relative to a good means-object (1935):

- The reliable cue is with a high probability not caused by other objects.

- The ambiguous cue is caused with a high probability by the given or by another object.
- The non-significant cue is caused with a small probability by either the given object or other specific objects.
- The misleading cue is only with a small probability caused by the given object and with great probability by another object.

Hence, a person will achieve his/her goal (1) if he/she picks good means-objects for reaching the positive goal and (2) if he/she selects reliable cues for this good means-object.

The main task of the organism is to correct the probabilities based on innate endowment and previous experience. These innate probabilities might hold in normalised environments but might be misleading in actual, given environments.

5.2.3. Probabilistic Perception Versus Thinking

In his 1954 Montreal symposium paper, Brunswik expanded his interests to thinking besides perception; whereas perception is considered a subsystem of cognition as is thinking. Both processes serve the same task of the organism, which is, to get to know its environment (Brunswik, 1934a).

Brunswik (1956) investigated the relationship between thinking and perceiving in respect to the error distribution of human behavior. According to Hammond (2001c), error in analytical cognition has been overlooked by research until then; however, for Brunswik it was a major way to investigate the cognitive strategies without using introspection (Goldstein & Wright, 2001). Brunswik (1948, 1954) investigated the error distribution of a judgment task in size constancy in two versions: The perceptual version was a typical case of perception, in which a stimulus situation was presented and all distance cues required for judging on the distance were left intact; the thinking version required reasoning with numerical indications to derive the correct result. 28 participants were tested with the perceptual version; 27 participants performed the thinking version. The answers' distribution of the task's perceptual version was compact and nearly normal, with the geometric mean at 8.95 cm (the correct answer was 8 cm), which corresponds to a logarithmic constancy ratio of .84. The distribution of the answers for the reasoning version was truncated with outliers: 13 answers out of 27 were exactly correct, but the geometric mean of the distribution was 14.7, which equals an arithmetic constancy ratio of only 0.12. The *SD* was more than 10 times bigger than the one obtained from the perceptual task's answers.

Brunswik (1948, 1954) concludes that thinking seems to be inferior to perceiving and explains it based on the error distribution and the processing speed: Perception relies on superficial, stereotyped cues of limited ecological validity and can, thus, never be perfect, it will always remain uncertainty-geared or probability-geared (Brunswik, 1956). In contrast, thinking is much less homogeneous, hence, certainty-geared. While reasoning linearly combines only a limited number of basic cues, resulting either in great precision or grotesquely scattered error, perceiving integrates many probabilistic cues without perfect ecological validity. Hence, thinking produces more erratic forms as does perceiving (Brunswik, 1955, 1956); thinking, however, also allows for perfection in a way perception is incapable of doing.

According to Brunswik (1956), perceptual processes are faster, which is due to the superficial way of using cues.

Many researchers are in line with the "power of perception" (see e.g., Dreyfus & Dreyfus, 1986; Gibson, 1966, 1979; Kirlik, 1989; Klein, 1989; Rasmussen, 1986; Reason, 1988, 1990), however, direct comparisons of perception with thinking or higher level cognitive processes have hardly ever been undertaken (but see Hammond, Hamm, Grassia, & Pearson, 1987).

5.2.4. Brunswikian Human Factors Research

The classical textbooks about human factors (Kantowitz & Sorkin, 1983) or engineering psychology (Wickens, 1992) do not reference any Brunswikian work. Only in recent years, task analysis techniques (Kirlik, 1995), design frameworks (Flach & Domingues, 1995), and methodological analyses (Kirlik, 1998; Vicente, 1997) explicitly apply Brunswikian ideas to modernize human factors' research. Also Rasmussen (1990) motivates an ecologically oriented human factors research, especially for high-risk systems. As human errors and mistakes can have devastating consequences, it is crucial to study how the proximal environment influences the distal context, which is the actual target of human interaction with technology.

One reason for the small amount of initial applications of Brunswikian research might be the low level of technological sophistication and automation in early human factors research, which did not allow the system operator manipulating distal variables and mastering the system accordingly. Instead, the system operator had to manipulate simple controls, which can be interpreted as proximal variables (Kirlik, 2001a; see also Rasmussen, 1990).

Researchers, who have applied the lens model approach in the field of telerobotics, are e.g., Sawaragi, Horiguchi, and Ishizuka (2001), as well as Horiguchi, Sawaragi, and Akashi (2000). Further, Miller, Kirlik, Kosorukoff, and Byrne (2004) used a lens model to model visual attention allocation; Bisantz, Kirlik, Gay, Phipps, Walker, and Fisk (2000) investigated operator decision-making performance in a complex, dynamic decision task. In both studies, the ability of human beings to apply consistent strategies for attention allocation or decision making was the critical issue (see also Section 5.2.1). Rothrock and Kirlik (2003) demonstrated that human beings can learn a non-linear strategy for decision making. In order to implement non-linear decision making strategies with the lens model approach, the authors used a combination of genetic algorithm techniques for rule-based representation and search, and multi-objective optimization for evaluating the fit of a rule-set. Bisantz and Pritchett (2003) investigated the degree to which unaided, human pilot judgment strategies were congruent with the strategies of an automated alerting system.

Although there is a growing amount of research applying the lens model formalism in the human factors community, a majority of the research is related to judgment and decision making.

5.2.5. Brunswik Versus Gibson: A Theoretical Comparison

Both, Brunswik (1956) and Gibson (1979) highlight the importance of the environment, but major differences can be found:

- Brunswik interprets perception and thinking as information processing, so that no direct perception takes place as advocated by Gibson.
- With his concept of affordances, Gibson proposes that distal variables are perceived directly. There is no need for information processing (Brehmer, 1984). Gibson was convinced that the distinction between proximal and distal variables is a false dichotomy (see Kirlik, 2001b).
- Gibson's world is not probabilistic; the human being has access to all required information (but see Gaver, 1991); whereas Brunswik (1937) considers incomplete or impoverished information.
- Brunswik (1956) does not only discuss perception, but in later years integrates perception in a theory of ratiomorphic or cognitive processes.
- The manipulanda of an object (see Tolman & Brunswik, 1935) resembles the concept of affordances as discussed by Gibson.
- The discriminanda of an object (see Tolman & Brunswik, 1935) reminds of Gibson's invariant information in the optic array specifying the affordances. However, compared to Gibson, the information specifying the object is of probabilistic nature in Tolman's and Brunswik's theory. Another difference is that the discriminanda explicitly specify the differences to other objects; whereas the invariant information only describes the unique information specifying an affordance.
- Tolman and Brunswik (1935) also consider the goal/motivation structure of the human being, which is not the case for Gibson.

Brunswik's theory of probabilistic functionalism (1957) and Gibson's ecological theory of direct perception (1979) do not only diverge theoretically, but also in their field of application, in which they have proven their validity: While Brunswikian research has shown its impact in the judgment and decision making community; Gibson's theory has contributed to understanding dynamic, visually guided action (Kirlik, 2001b). Still, Brunswik's lens model (1952) and the underlying idea of analyzing the human-environment system and Gibson's perceptual specification of the environment in his concept of affordances yields important insights into how skilled human-environment interaction can be modeled (Kirlik, 1995).

5.2.6. Theoretical Relevance of Probabilistic Perception and Thinking in the Context of Information Acquisition

Brunswik proposed ratiomorphic processes requiring some kind of information processing. More specifically, he distinguished between thinking and perceiving (Brunswik, 1954): Thinking is applied when the available, perceptible cues do not allow judging on a distal variable. The information, which is perceived is, in any case, equivocal, hence, direct perception as proposed by Gibson (1979) is not possible. However, both theories can be combined as follows:

If the adaptation process to an environment has not yet fully taken place, i.e., the observer is not yet fully adapted to the surroundings, the probabilistic process of perception takes place according to Brunswik (1937). However, if the conditions allow for reaching the final stage of perfect adaptation and further adaptation takes place, the probabilistic process of perception fades and direct perception takes place. In some cases, it is impossible to reach that final stage of perfect adaptation, i.e., when the information is not consistent or the observer does not have the required cognitive abilities to work out, which cues are optimal representatives, and how these cues need to be combined (see Section 7.2.2).

This description implies the cognitive processes going on when adapting to a situation: the information in the environment of interest must be defined (i.e., the cues) and its importance (i.e., its ecological validity) must be determined. Hence, at the beginning of an adaptation process, i.e., when thinking takes place, the proximal variables are perceived and combined based on reasoning, feedback processes or experience. When adaptation proceeds, perception of the correct cues takes place, which are combined based on their ecological validity and, last, when direct perception occurs, the distant variables are directly perceived without the need for the aforementioned information processing. This distant variable, that is then perceived, is the causal texture of the environment, consisting of the discriminanda, manipulanda, and utilitanda of all available means-object. This causal texture is referred to as *situation*. The proximal cues pointing to these characteristics of the means-objects are no longer perceived.

The lens model framework has been criticized as not explicitly representing actions (Brehmer, 1986; Kirlik, 1995; but see Brunswik, 1952; Hammond, 1966; Tolman & Brunswik, 1935). Brehmer (1986) argues that the lens model framework might model action selection based on judgment and choice. However, Hammond, Stewart, Brehmer, and Steinmann (1975) state that a judgment activity is only initiated when the available information does only probabilistically specify a criterion and when actions for gaining more diagnostic information are not available.

The relationship of perception to human behavior is, in this context made based on the distal variables, which are expected to have a direct link to relevant behavior (for further discussion, see Section 6).

5.3. Intuition and Analysis

5.3.1. Cognitive Continuum Theory

Hammond, Hamm, Grassia, and Pearson (1987; Hammond, 2001a, 2001b; Hammond, Hamm, & Grassia, 1986) have extended the theoretical and empirical work about Brunswik's (1954) ratiomorphic processes in their cognitive continuum theory (Goldstein & Wright, 2001). Instead of proposing two modes of processing, Hammond and his colleagues reject the dichotomy and assert that thinking and intuition are the extreme modes of thought and that a continuum of quasi-rational processes is in between (Brunswik, 1956; Goldsberry, 1983; Hammond, 1955, 1966, 1982; Hammond & Brehmer, 1973). According to Hammond (2001a), all cognitive activities move along this intuitive-analytical continuum over time (for a summary and comparison of the characteristics of intuition and analysis, see Table 2).

Parallel to the cognitive processes, tasks can also be located on a continuum depending on the type of cognitive processes they evoke. Payne (1982) confirms the importance of considering task properties when analyzing judgment and decision making. Once, cognitive processes are located on their continuum, they interact with tasks sorted on a similar continuum in predictable ways (see Friedman, Howell, & Jensen, 1985 for evidence that task properties induce corresponding modes of cognition). To investigate the consequences of a match/mismatch between the task's localization on the continuum and the cognitive processes, descriptive terms must be determined (1) to locate a person's cognitive abilities on the cognitive continuum and (2) to locate a task on the task continuum.

Table 2

Characteristics of Intuition and Analysis (Adapted From Hammond, Hamm, Grassia, & Pearson, 1987)

	Intuition	Analysis
Cognitive control	Low	High
Rate of data processing	Rapid	Slow
Conscious awareness	Low	High
Organizing principle	Weighted average	Task-specific
Errors	Normally distributed	Few, but large
Confidence	High confidence in answer, low confidence in method	Low confidence in answer, high confidence in method

Hammond, Hamm, Grassia, and Pearson (1987) propose that a decision maker will employ intuitive cognition (see Table 3), if (1) the task has many redundant cues, (2) the cue values are continuous, (3) the cues are displayed simultaneously, (4) the cues are measured perceptually, and (5) the participant has no explicit principle, scientific theory, or method for organizing the cues into a judgment available. The decision maker will then assign unreliable, subjective, ecological validities to each cue, which will lead to low cognitive control, i.e., intuition. The authors even predict that the participants will implicitly apply a weighted sum or weighted averaging method of organizing the information, because it has been shown that weighted averaging is the most robust aggregation method (Dawes & Corrigan, 1974). Robustness means high accuracy despite (1) incorrect assignments of weights, (2) poor approximation to the correct function forms between cue and criterion, and (3) poor approximation to the correct organizing principle. Tasks with both intuitive and analytical properties may induce a compromise between intuition and analysis (see Brunswik, 1952, 1956; Hammond, 1955; Hammond & Brehmer, 1973).

Table 3

Intuition- Versus Analysis-Inducing Task Characteristics (Adapted From Hammond, Hamm, Grassia, & Pearson, 1987)

Task characteristics	Intuition-inducing	Analysis-inducing
Number of cues	Large (>5)	Small
Measurement of cues	Perceptual	Objective, reliable
Distribution of cues	Continuous, highly variable distribution	Unknown distribution, dichotomous cues, discrete values
Redundancy among cues	High	Low
Decomposition of task	Low	High
Degree of certainty in task	Low	High
Relation between cues and criterion	Linear	Nonlinear
Weighting of cues in environmental model	Equal	Unequal
Availability of organizing principles	Unavailable	Available
Display of cues	Simultaneous	Sequential
Time period	Brief	Long

A distinction between surface and depth characteristics of tasks must also be drawn (Hammond, Stewart, Brehmer, & Steinmann, 1975; Simon, 1979): The depth variables refer to the covert relationships among the variables within the task; whereas surface variables refer to the overt display of the task variables to the subject. Since both, surface and deep task characteristics can be described in terms of the same set of task properties, their congruence can be measured by their respective locations on the task continuum: While the depth characteristics determine the rough location on the task continuum, the fine-tuning and exact location within the roughly defined categories is decided on the basis of the task’s surface characteristics.

The assumptions made in the cognitive continuum theory were tested in a study of 21 highway engineers: Hammond, Hamm, Grassia, and Pearson (1987; Hammond, Hamm, & Grassia, 1986) analyzed (1) if task properties induce corresponding cognitive properties, (2) if analytical cognition is always superior to intuitive and quasi-rational cognition employed by the same person, (3) if analytical cognition is apt to produce extreme errors to a greater degree than do the other cognitive styles, (4), if achievement is smaller, when the deviation between the task characteristics and cognitive style is bigger, and (5) if achievement is greater, when the congruence between the surface and depth characteristic is smaller.

In order to analyze these research questions, Hammond, Hamm, Grassia, and Pearson (1987) used three judgment tasks: (1) highway aesthetics (intuition-inducing), (2) highway safety (quasi-rationality inducing), and (3) highway capacity (analysis-inducing). For example, judging on highway aesthetics induces intuition because the participants depend largely on perceptual material and are not required to make complex calculations. Different surface characteristics of the judgment tasks were used in order to induce different cognitive controls within the broad category evoked by the depth characteristics:

To increase intuition for all three judgment tasks, the engineers were shown film strips. Film strips are expected to be intuition-inducing as all cues need to be derived perceptually. Further, the film strips give numerous cues, which are frequently redundant and only contemporaneously displayed. The values of the cues are continuous and normally distributed. Furthermore, there was no time for organizing the displayed information in an analytic way.

To increase the quasi-rational processes, bar graphs were presented. These bar graphs induce intuition within the categories of all three depth characteristics, as the cues are displayed visually and contemporaneously, the cues are redundant, continuous and normally distributed. At the same time, this presentation induces analysis, because the number of cues is reduced from a large-unknown number to a specific set, each cue is visually separated from each other and its numerical value clearly indicated.

To increase analytic cognition, the engineers were asked to use mathematical formulas for judging on highway aesthetics, safety, and capacity.

Nine tasks resulted and for each a task continuum index was calculated based on the number of cues presented, the redundancy among the cues, the reliability of cue measurement, the degree to which the task is decomposed, the availability of an organizing principle, the degree of nonlinearity in the optimal organizing principle, the extent to which the cues are weighted equally in the optimal organizing principle for the task and the degree of certainty of the organizing principle.

Besides the task continuum index, the authors calculated a cognitive continuum index based on the cognitive control, the organizing principle, error distribution, and differential confidence. For the film strip and the bar-graph conditions, the cognitive control was calculated as the linear predictability of the engineers' judgments (see Hammond & Summers, 1972). As analytical cognition is expected to be nonlinear, analytical cognitive control is measured by the difference between a nonlinear and a linear model. Differential confidence refers to the difference between the engineer's confidences in his/her method and in his/her answers.

The results confirm the underlying theory:

- A correlation analysis revealed that each participant's cognitive continuum index for each of the nine task conditions was correlated with the location of the tasks on the task continuum index. The mean correlation (*z*-transformed) is 0.51, which is significantly different from zero ($t = 6.63$, $p < .01$, $df = 20$).
- Analytical cognition is not always superior to intuitive and quasi-rational cognition employed by the same person. Regarding highway capacity, the test of predicted order for achievement was significant with $\chi^2 = 9.63$ ($p < .01$), for highway safety the test was not significant with $\chi^2 = 0.05$, for highway aesthetics, it was significant in the reversed direction with $\chi^2 = 15.43$ ($p < .01$).
- The errors are more serious as the depth characteristics become more analytical, which confirms the results of Brunswik (1956) or Hamm (1988).

- Achievement is better when cognitive properties correspond to task properties (see also Friedman, Howell, & Jensen, 1985). The mean of the distribution of each participant's correlation (*z*-transformed) between the absolute value of the difference between the task continuum index and the cognitive continuum index and achievement is -0.37 +/- 0.07, which is significantly different from zero ($p < .01$, $df = 20$, two-tailed).
- Congruence between surface and depth characteristics does only weakly enhance achievement. The mean of the distribution of each participant's correlation (*z*-transformed) between achievement and the measure of congruence is 0.18 ($SD = 0.06$), which is significantly different from zero ($p < .01$, $df = 20$, two-tailed).

5.3.2. Theoretical Relevance of Intuition and Analysis in the Context of Information Acquisition

Hammond, Hamm, Grassia, and Pearson's (1987) cognitive continuum theory is an advancement of the theory of ratiomorphic processes (see Brunswik, 1957). Hammond et al. mainly focused on the environment and investigated which task characteristics provoke which cognitive activity. Parallel to the cognitive activities, they sorted the tasks on a similar continuum depending on which cognitive activity they cause. The cognitive activities intuition, quasi-rational processes and analysis were distinguished.

Traditional research usually compares a person's judgments with person-independent, formal models such as Bayes' theorem, a multiple regression equation, or other rules from the conventional probability calculus (see e.g., Einhorn & Hogarth, 1981; Hammond, McClelland, & Mumpower, 1980; Jungermann, 1983; Kahneman, Slovic, & Tversky, 1982; Pitz & Sachs, 1984). Information about the relative efficacy of intuitive or analytical cognition is not provided by this type of research. Direct comparisons of different strategies within persons are, in contrast, proposed by Hammond, Hamm, Grassia, and Pearson (1987).

The cognitive continuum theory highlights the importance of the task in information acquisition and states that differing task characteristics can provoke different levels of cognitive control. Research on skill acquisition confirms the task's role: Considering the actor's stage in a skill acquisition and/or situation adaptation process (see also Section 7.2.2) can explain the characteristics of analysis and intuition as proposed by Hammond, Hamm, Grassia, and Pearson (1987):

- The need for cognitive control shrinks with the number of times the actor has been confronted with this or a similar, positive transfer-provoking situation/task, if the task/situation is consistent and the actor's cognitive abilities are sufficiently high. This is the case, as achievement is, with practice less dependent on cognitive skills (see e.g., Ackerman, 1988). With the skill acquisition/adaptation process, the impact of this ability on performance or achievement shrinks.
- The rate of data processing depends on the stage of the adaptation process as well: With practice, the impact of the processing capacity on performance decreases, while the performance is more and more determined by the psychosensoric abilities (Ackerman, 1988), which is the ability to solve relatively easy tasks as fast as possible (Jäger, 1982). A high level of information processing, as required at the initial state, is no longer necessary with progressing skill acquisition.
- When a skill is highly automated, conscious awareness decreases (Fitts, 1964; Fitts & Posner, 1967; Rasmussen, 1983, 1986, 1990).

Hence, the research on skill acquisition provides a theoretical basis for the variables determining the task's location on the task continuum index: Two groups of variables can be distinguished. On the one hand, characteristics of the actor (i.e., relevant cognitive abilities) determine the actor's stage of the situation process and the subjective degree of difficulty of the task (see Figure 5). A complex task will be considered as more difficult for a less able participant. Besides, a more able participant will adjust to the given situation quicker compared to a less able participant. As the task characteristic is dependent on the actor, it is referred to the *subjective task characteristic*. The *objective task characteristic* is the consistency of a task (see also Section 7.2.1). If a task is inconsistent, adaptation does not take place and the task keeps provoking a high level of cognitive control.

In accordance with the cognitive continuum theory, it is expected that the task's localization on the task continuum index provokes a different level of cognitive control. These are also sorted on a continuum, ranging from analysis, intuition to direct perception.

Summarizing, a difficult task will only for the experienced actor/observer provoke intuition but for the novice analytical cognition, if the task is consistent.

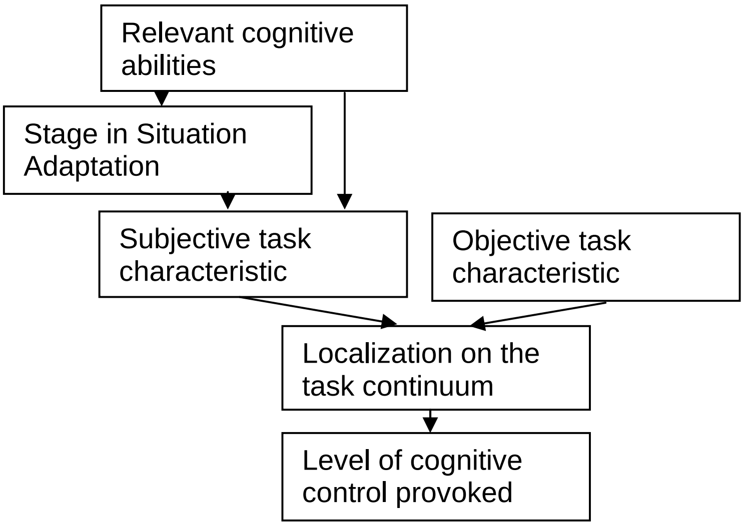

Figure 5. Relationship between the determinants of situation adaptation, subjective and objective task characteristics, the task continuum and the level of cognitive control provoked.

5.4. Perceptual Processing

5.4.1. Theory of Skilled Human-Environment Interaction

Kirlik (1989, 1995; Kirlik, Walker, Fisk, & Nagel, 1996) argues that skilled performance relies heavily on perception, which means that experts perceive opportunities for action rather than having to infer appropriate actions based on cognitively demanding information processing. This deeper information processing is only required when the information in the environment is impoverished, or new, unfamiliar, or unanticipated events occur. This is why expert behavior can be modeled based on a parsimonious model relying on action and perception.

According to the suggestions of human factor's researchers (e.g., Baron, Kruser, & Huey, 1990; Sheridan & Ferrell, 1974) that human behavior is too unconstrained to be modeled efficiently without considering the environment, Kirlik (1995; Kirlik Miller, & Jagacinski, 1993) described the environment based on a dynamic set of constraints on productive action and identified the available information capable of specifying these constraints (see also Simon, 1969).

Describing a situation as optimal for a specific action ignores the issue whether an action is in accordance with the performer's goals. This is why the authors used affordance values for each possible action. It was assumed that the actor will realize the action with the highest affordance value. A comparison between the resulting model and the experts' behavior provided a good fit: 58 of 66 similarity tests were not significant (all comparisons were *t*-tests with $p < .05$[1]). Deeper cognitive processes such as problem solving were not required as, the experts were not confronted with new, unfamiliar situations or impoverished information. Hence, cognitively intense methods for action selection are only used when effective perception-action selection is not available (Kirlik, 1995).

5.4.2. Theoretical Relevance of Perceptual Processing in the Context of Information Acquisition

The research on perceptual processing states that skilled performance is highly dependent on perceptual processes and that higher cognitive processes are only required when the information is impoverished or not sufficiently familiar. This confirms the in Section 5.2.6 made assumption that the environment or the available proximal cues might only be probabilistic, because the observer is not yet an expert for the situation at hand. An exception is the inconsistent situation which does not allow adaptation. Hence, cognitively demanding strategies are only applied by novices and when the situation does not allow developing expertise (i.e., the situation provides inconsistent information, see Section 7.2.2).

In contrast to the previously introduced theories of Gibson (1979), Brunswik (e.g., 1956), and Hammond, Hamm, Grassia, and Pearson (1987), Kirlik (1995)

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[1] Methodological problems, such as an alpha-inflation, result because of the high number of *t*-tests performed in this study.

introduces the concept of an affordance value, which is closely related to the motivation underlying behavior. It is assumed that the situation does not uniquely specify an optimal action, but a set of possible behaviors based on the, by the situation defined constraints. Based on the motivation or the affordance value, an action is chosen and realized.

5.5. Skills-, Rules-, and Knowledge-Based Control of Behavior

5.5.1. Theoretical Basis of Cognitive Engineering

In his approach to cognitive engineering, Jens Rasmussen (1983) introduced the Skills, Rules, and Knowledge (SRK) model as a tool for describing how human beings interact with their environment and especially complex technological systems. Parallel to Kirlik (1995), Rasmussen argues that the environment and especially constraints limit human behavior. These constraints result out of interrelated affordances available to the user/actor and can be represented in different ways (Rasmussen, 1983, 1986, 1990) reflecting different levels of human behavior and performance (see Figure 6):

- Skill-based behavior is highly automated, unconscious behavior, controlled by the perceptual-motor system. Choosing between action alternatives is not required, but fine-tuning the skills in question and/or detecting near-errors are necessary. For this purpose, the senses are directed towards environmental aspects, which are used as *signals* for updating an internal map (Rasmussen, 1983). This internal map is available because of earlier experience (Vicente & Rasmussen, 1992). It will anticipate future events and prepare the organism for adequate actions. The features in the environment relevant for updating the internal map are perceived directly. Rasmussen compares this process with Gibson’s (1966) atonement of the neural system, which underlies the direct perception of invariant information in the optic array.
- Rule-based behavior is controlled by procedures, which are rules of thumb or effective know-how. These rules re-place analytically derived cues for action with empirically derived, informal cues that discriminate between the perceived action possibilities. These rules may have been acquired based on

experiments, communicated by other persons, or prepared by problem solving. The information in the environment is perceived as *signs*, which activate, modify or update predetermined rules based on prior experience. Hence, effective rule-based behavior depends on the correlation of cues and successful actions. In order to guarantee smooth behavior, attention will look ahead to identify the rules of interest for actions in the near future, and it will look back to get feedback from past actions.

- Knowledge-based behavior takes place in unfamiliar, unanticipated situations, in which neither rules nor skills are available (Vicente & Rasmussen, 1992). The human being formulates goals based on analyzing the environment and his/her overall aim(s). This explicit goal formulation forms an important distinction to rule-based behavior and is used to develop plans and select an appropriate one. For this purpose, the effects of the potential plans are tested based on internal representations or by experiments. The basis for developing these plans is a proper internal symbolic representation of the environment, in which concepts related to the functional properties of the environment can be used for reasoning. Hence, *symbols* need to be perceived from the environment. The efficiency of this procedure depends on the availability of a larger repertoire of different mental representations from which plans can be generated ad hoc.

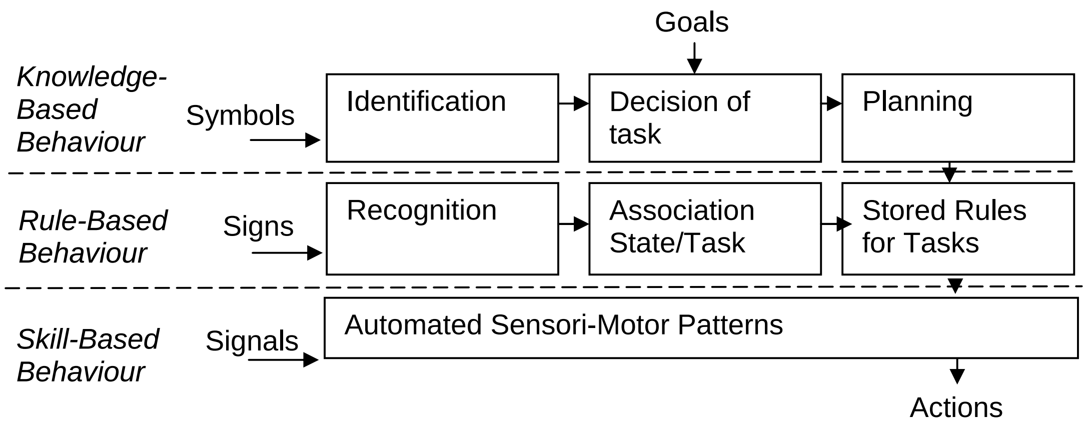


Figure 6. Levels of cognitive control (on the basis of Rasmussen, 1983).

The three levels of cognitive control can be grouped into two general categories (see e.g., Reason, 1990; Vicente & Rasmussen, 1992). Knowledge-based behavior is related to analytical problem solving based on a symbolic representation; whereas the skill-based and rule-based behaviors are concerned with action and perception. The distinction is similar to other human performance frameworks as well (see e.g., Reason, 1988).

The variable influencing which model of cognitive control will be applied depends on the novelty of the task (Leplat, 1988; Rasmussen, 1983, see also Section 5.3), i.e., adaptation to a situation takes place. Rasmussen (1983) argues that with increasing familiarity of the situation, the behavioral patterns of the higher cognitive levels do not become automated skills. Instead, the automated patterns evolve while the higher cognitive levels control the behavior. While practicing, the higher level controls deteriorate, and the lower levels take over control. This transmission period might be error-prone, because the skilled-levels of behavior are not yet fully developed, but the higher cognitive controls deteriorate. Hence, adaptation in the SRK model is a qualitative change of the different cognitive processes involved.

The research on the SRK model was enhanced and incorporated in Rasmussen's decision ladder (1986), which represents decision making as a sequence of information processing steps and resultant stages of knowledge. These steps include the following ones (see Figure 7):

- The decision maker first detects a need for an action. A state of alert results.
- In a next step, the decision maker/actor observes the system and gathers data. A set of observations result.
- Based on the set of observations, the data are analyzed in order to identify the present state of the system. The system's state is anticipated.
- The decision maker evaluates the state of the system, anticipates possible consequences and relates them to the existing goals. A target state is defined, into which the system needs to be transferred.
- The task has to be chosen to achieve the target state of the system. The available resources must be kept in mind.
- A sequence of actions is planned, i.e., the proper procedure is determined.
- This sequence is executed.

These decision making steps related to the SRK model as follows (see also Figure 7):

- The rational, knowledge-based decision making depends on knowledge about the internal, functional, and intentional properties of the system. This way is represented by completing all steps of the decision ladder. The upward leg of the decision ladder (see Figure 7) represents the situation analysis and judgment; whereas the downward leg demonstrates the steps required for implementing the decision.

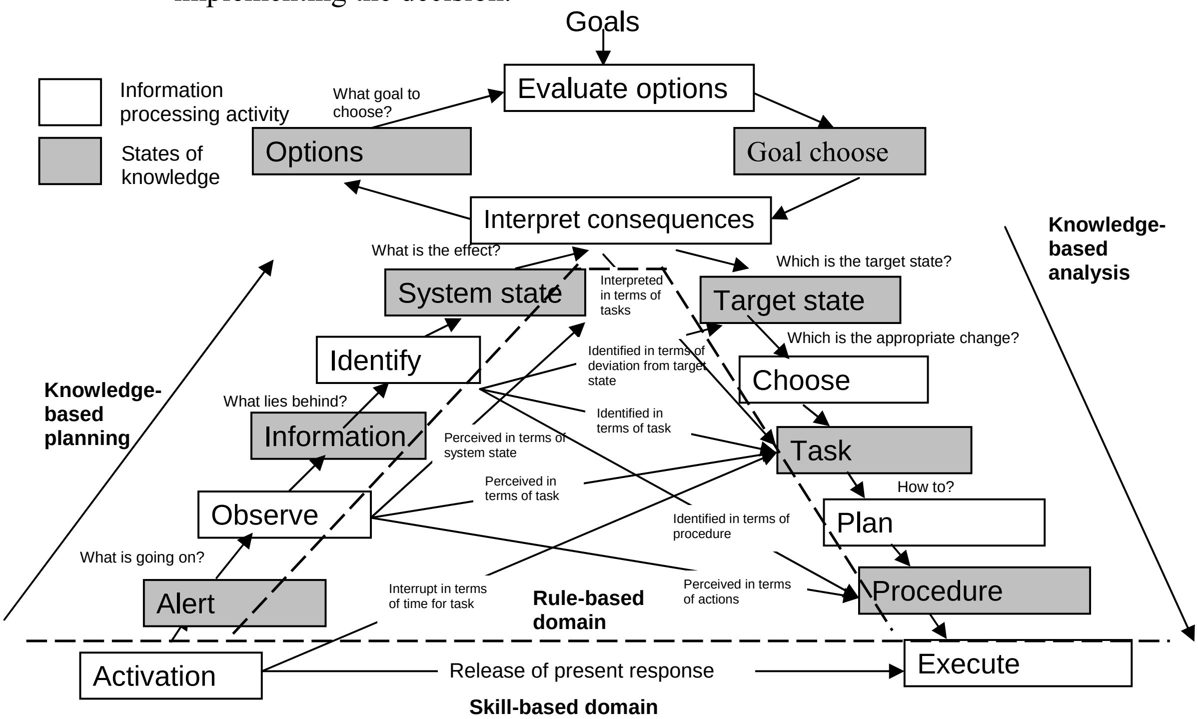


Figure 7. Decision ladder and its relationship to the SRK model (adapted from Rasmussen, 1986).

- The heuristic, rule-based decision making is applied by actors with experience with the situation and depends on shortcuts in the basic decision sequence. This type of decision making relies on induction. Familiar states of the environment are associated to actions that have been effective in previous situations (Rasmussen, 1993). In this case, only the cues that are necessary to allow discrimination between actions are perceived. Rasmussen proposes that the control of activities can also be structured along a cue-action hierarchy: Cues at a high level activate the consideration of a particular goal, while other cues define the relevant task and its action alternatives. At a more detailed level, cues might activate the individual action sequence.

- The highly skilled decision making behavior represents the automated motor response after having detected the need for an action.

5.5.2. Application in Human Factors and Resulting Cognitive Engineering

As Rasmussen (1983, 1986, 1990) was mainly interested in the control of nuclear power plants and how to avoid errors of service (especially slips and errors of intention), he pursued a practical approach and did not directly test his theoretical assumptions, but the implications of them, i.e., especially the derived design guidelines. Exceptions refer to studies conducted to test the decision ladder e.g., in the context of hospitalization diagnostic sessions (Rasmussen, Pejtersen, & Goldstein, 1994), in the scheduling of productions (Higgins, 2001; Sanderson, 1991) or in the military domain such as broad command and control networks (Chin, Sanderson, & Watson, 1999).

One of the guidelines derived from Rasmussen's approach to cognitive engineering (1983, 1986) is the Ecological Interface Design (EID; Rasmussen & Vicente, 1989; Vicente, 1995; Vicente & Rasmussen, 1992). The main goal of the EID is to design an interface, which provides optimal support for each level of cognitive control (Rasmussen & Vicente, 1989; Vicente & Rasmussen, 1988) and which does not force the users to be engaged on a higher level of cognitive control than required by the task. To support all levels of control, the following guidelines are provided (Vicente & Rasmussen, 1992):

- The skill based-behavior can be supported best if the interface provides the means to act directly on the display. Further, the information on the display should be isomorphic to the structure of movements.
- In order to support rule-based behavior, the interface should provide cues or signs which optimally map the constraints of the work domain on the display.
- To support knowledge-based behavior, the interface should display the relational properties of the work domain in the form of an abstraction hierarchy, which serves as an externalized mental model (see e.g., Vicente & Rasmussen, 1990). This mental model provides the support for planning activities and thought experiments.

The abstraction hierarchy (Rasmussen, 1979, 1983, 1985, 1986), which belongs to the class of the stratified hierarchies (Mesarovic, Macko, & Takahara, 1970), allows representing the constraints of a work domain in such a way, which optimally supports the operator in dealing with unanticipated events. Its number of levels differs depending on the work domain of interest, but Rasmussen (1979, 1983, 1985, 1986) distinguished five levels:

- The functional purpose describes the objectives of the system.
- The abstraction function refers to the causal structure, e.g., information flow, energy flow, etc.
- The generalized function represents standard functions and processes, e.g., control loops, heat transfer, etc.
- The physical function consists of the physical processes or equipment, by which the functions are implemented (e.g., the electrical, mechanical, chemical processes of components and equipment).
- The physical form refers to the material configuration of the system.

When moving from the top to the bottom of the hierarchy, reasons for the existence of the system step back, but the physical basis describing the capabilities of the resources and the causes of malfunctioning are added.

This abstraction hierarchy provides the operators of complex systems with an informational basis for coping with unanticipated events as it is a psychologically valid representation for problem solving (Vicente & Rasmussen, 1990, 1992). The latter has been demonstrated empirically by Selz (1922). If the abstraction hierarchy is used to present this information in the interface, it optimally supports the user in problem solving (see e.g., Vicente & Rasmussen, 1990).

Vicente has analyzed the utility of these guidelines (1991) and yielded initial, experimental support, as did Christoffersen, Hunter, and Vicente (1997). Further support was given by Vicente, Christoffersen, and Pereklita (1995). The authors developed two interfaces for a thermal-hydraulic process simulation: one based on the traditional format containing information about the physical form, the physical functions, and the functional purpose, another based on the EID, which also contained the information about higher-order functional variables (generalized functions and abstract functions) which was missing in the traditional interface. Twelve theoretical experts (students in mechanical or nuclear engineering) and twelve novices were tested in two successive sessions for each interface. Each session consisted of ten trials with five replications of each trial type (steady state of the process simulation, change in the reservoir's volume, leak of the reservoir, blocked valve and change in the water temperature). For each trial, a sequence of the behavior of the process simulation was demonstrated for a duration of 25-30 seconds, after which the participants had to recall 34 process variables and answer a set of structured questions evaluating the diagnosis of the process simulation. The predicted superiority of the EID-based interface over the traditional interface for the diagnosis accuracy was assessed for each individual. An aggregation over participants was accomplished by the number of participants whose behavior conformed to the prediction. A sign test was calculated in order to test the diagnosis accuracy for the experts and novices: The results for the experts were significant for two out of three levels of analytic reasoning with $p < .01$ and $p < .01$. The results for the novices were not significant, which demonstrates that the experts did benefit more from the EID-based interface as did the novices.

A theoretical enhancement of the EID is, for example, the ecological information system, which is concerned with loosely coupled work domains with a high degree of strategic task uncertainty and self-organization (for further information, see Pejtersen, 1984, 1994).

5.5.3. Theoretical Relevance of Skill-, Rule-, and Knowledge-Based Control of Behavior in the Context of Information Acquisition

The cognitive engineering approach mainly aimed at gaining knowledge about the control mechanisms of human behavior in order to better understand human errors and provide support to increase the dependability of complex human-machine systems (e.g., Rasmussen & Vicente, 1989). For this purpose, the SRK model differentiates between three levels of cognitive control, underlying mechanisms and information in the environment activating the different levels of control. The SRK model herewith extends Tolman and Brunswik's (1935) distinction between information and signs; instead Rasmussen (1983, 1986, 1990) defines signals, signs, and symbols. While signals directly activate motor patterns, signs are informal cues activating and modifying rules. Symbols are related to functional properties of the environment allowing for reasoning about the best action.

The different mechanisms Rasmussen (1983, 1986, 1990) proposes underlying the three levels of cognitive control replace each other with increasing familiarity of the situation. This opposes especially the cognitive continuum theory's assumption (see Section 5.3) that there is a continuum between analysis (i.e., knowledge-based behavior according to the SRK model) and intuition (i.e., skill-based behavior).

As Rasmussen already states (1983, 1986, 1990), the skill-based behavior resembles Gibson's direct perception (1979, see Section 5.1). However, Gibson would have opposed the information processing component, which Rasmussen assumed in the form of mental models. While Rasmussen investigated the control of nuclear power plants, Gibson analyzed perceptual processes, which could have provoked this difference. An internal model might have been redundant for the less complex tasks as analyzed by Gibson. The impact of task complexity has been demonstrated in a similar field, analyzing especially the rule-based simplification strategies (but see also Section 5.3). In the field of decision making, compensatory decision making strategies, e.g., linear-additive strategies requiring searching for cues, weighing them and adding the weighted cues for deriving an overall value (see e.g., Kurz & Martignon, 1998), have been compared with non-compensatory decision making strategies, which are rule-based simplification strategies (e.g., see Gigerenzer, Hoffrage, & Kleinbölting, 1991; Gigerenzer, Todd, & ABC Research Group, 1999). The latter require lower information search and information integration demands (see e.g., Gigerenzer & Goldstein, 1996; Rothrock & Kirlik, 2003). Research has shown that decision makers change their strategy basically depending on task complexity (see e.g., Payne, 1976) and time stress (e.g., Payne, Bettman, & Johnson, 1988; Wright, 1974). Rothrock and Kirlik (2003) state that increasing the task complexity (e.g., the number of cues, the number of possible alternatives) and time stress tend to increase the probability that people adopt cognitively less demanding strategies for making decisions. However, it is important to note that the non-compensatory strategies do not necessarily lead to worse decisions (Dawes, 1979). In contrast, these rule-based strategies yield surprisingly good and robust results (Gigerenzer & Kurz, 2001; Kirlik, Walker, Fisk, & Nagel, 1996). The comparisons between non-compensatory decision making strategies when put parallel to the rule-based level of cognitive control and the compensatory decision making strategies, interpreted as the knowledge-based level of control, support the research conducted by Hammond, Hamm, Grassia and Pearson (1987) or Brunswik (1948, 1954): The certainty-geared strategies can be more accurate compared to intuition but yield the danger of going off in the wrong direction resulting in a greater error distribution. The effect that increasing the task complexity makes the decision maker apply cognitively less demanding strategies can be explained based on the impact of motivation on the level of cognitive control applied (see Section 7.1.2). Increasing the task complexity might result in too excessive demands, which might reduce the motivation and, thus, the willingness to apply cognitively demanding strategies of control.

Summarizing, the distinction made between skill-based, rule-based and knowledge-based control of behavior can be mapped to the continuum described e.g., by Hammond, Hamm, Grassia, and Pearson (1987) between analysis and intuition. While the skill-based control of behavior greatly resembles the intuition or perception, the knowledge-based control is closely related to the analysis as described by Hammond, Hamm, Grassia, and Pearson (1987). The continuum of information acquisition is, by the SRK model more thoroughly described in its complete range. Hence, with increasing exposure to an initially new situation, the level of cognitive control applied by the actor/observer moves continuously from knowledge-based to direct perception of the appropriate action to be taken. Due to research results in the field of skill acquisition (see Section 7.1), it is assumed that the classification of e.g., skill-based and rule-based behavior is an artificial one and that they pass into each other with increasing familiarity of the situation, if the subjective and objective task characteristics allow situation adaptation (see Section 5.3.2).

In contrast to the other theories described, a clear definition of the cognitive processes underlying the three levels of cognitive control is given: During the knowledge-based behavior, an internal representation of the environment and the activity is built. With practice and mental simulation this map of the environment is more elaborated (i.e., the causal texture evolves), so that informal variables or cues are used as anchors pointing to heuristics guiding behavior. Rule-based behavior takes place. In the last step of the adaptation process, the internal representation has been fully elaborated, the complex situation is perceived in a highly differentiated way and an appropriate activity chosen directly to achieve the goal in question.

5.6. Recognition and Analytical Mode of Decision Making

5.6.1. Recognition-Primed Decision Making

Klein (1989, 1993; Klein & Calderwood, 1991) analyzed expert decision making behavior in real-life by studying fire-fighting commanders based on their behavior in non-routine events. Since the events were non-routine, it was expected that decision making would be based on analytical processes; however, the experts often relied on an easier, less cognitively demanding mode of decision making.

To explain decision making, the authors distinguished a recognitional and an analytical mode of decision making. The first depends on rules; whereas the second reflects knowledge-based behavior. The expertise required for applying the recognitional way of decision making allows directly generating a plausible and promising action alternative. In contrast, a serial comparison of all decision alternatives is needed when no experience is available, which is, when the analytical decision mode is applied. The comparisons stop, when a satisfying solution is reached (Simon, 1955). Hence, decision making depends on two processes – situation assessment and mental simulation. Situation assessment, on which recognition is based, is required to generate a possible course of action, mental simulation in order to evaluate the courses of action (Klein, 1993).

Three scenarios can be distinguished (see Figure 8):

The simple match is the scenario, in which the situation is recognized and the obvious reaction can be implemented directly. A decision on an action is not required. The recognition and/or situation assessment has four aspects (Klein, 1989): (1) understanding the types of goals, which can be accomplished in this given situation,

(2) increasing the salience of the cues that are important for situation assessment, (3) forming expectations, which serve as a check for situation assessment, and (4) identifying the typical actions to be taken.

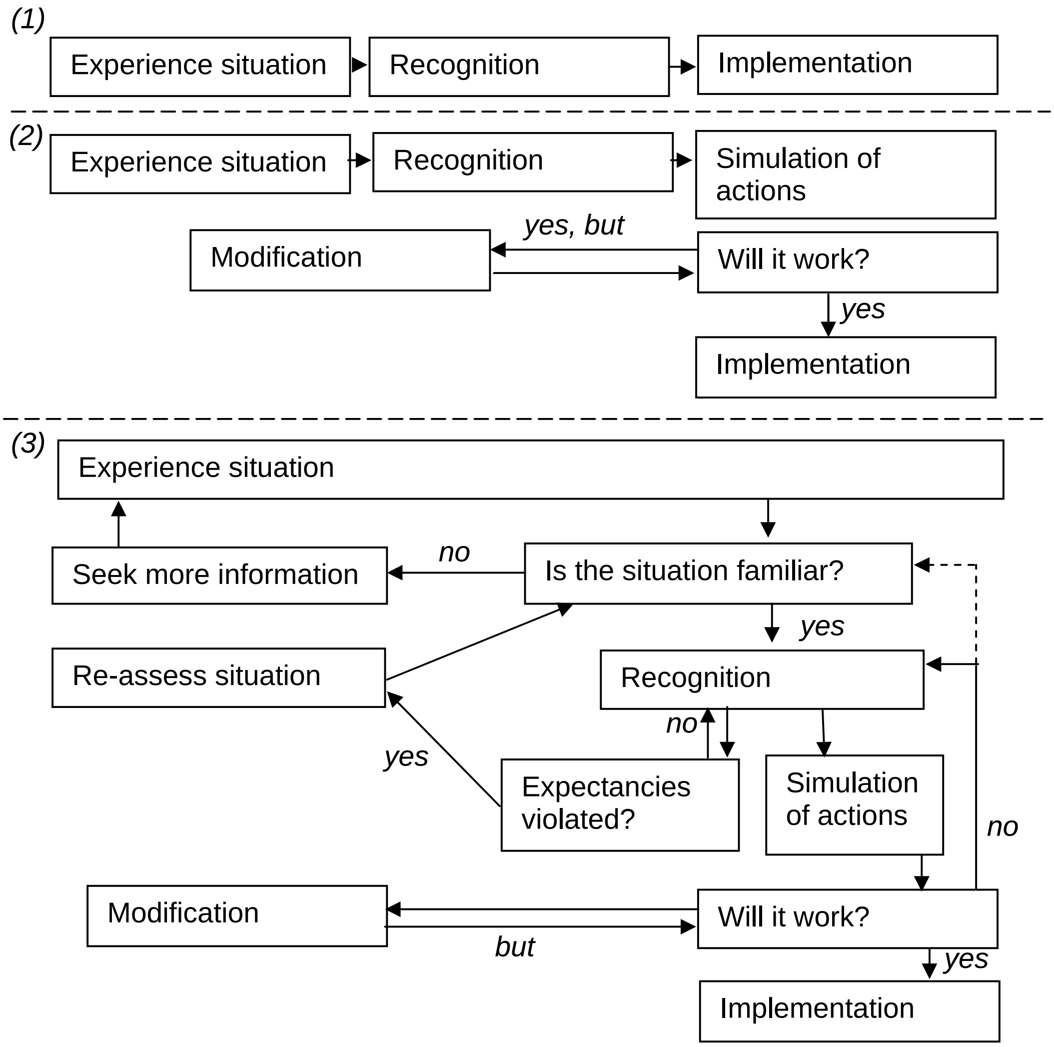


Figure 8. Recognition-Primed-Decision Model showing the different decision strategies, i.e., (1) the simple match, (2) the analytical mode of decision making, and (3) the complex recognition-primed-decision strategy (adapted from Klein, 1989).

A more complex case is the one in which the situation has been recognized, but some kind of mental simulation is required in which imagery is used to uncover problems with carrying out a possible action. This is the analytical mode of decision making.

The most complex case, i.e., the complex recognition-primed-decision making (RPD) strategy, is the one, in which situation assessment and mental simulation are more demanding. Experiencing a situation does not necessarily result in recognition, so that seeking more information is required. This might also be necessary, when expectations are violated, which were generated based on experience. Hence, recognition does not clearly define an action to be implemented. The mental simulation of possible reactions might further require some modifications to the actions of interest.

5.6.2. Recognition and Analytical Mode of Decision Making in the Context of Information Acquisition

The RPD model is distinct from other, traditional decision making models in a number of ways: Most important is the focus on the situation and situation assessment. The RPD model focuses more on understanding a situation than comparing different alternatives, while other decision making theories have either focused on the individual process of decision making independent from the situation or on the ideal process of decision making, but have ignored the impact of the situation and experience on the decision making process.

The RPD model is closely related with the SRK model (see Section 5.5. and Rasmussen, 1983, 1986, 1990). The simple match, Klein (1989, 1993) described, is the situation in which experience allows directly implementing an action. This equals the skill-based level of cognitive control. Further, the concepts of situation assessment and mental simulation to test the impact of different action possibilities resemble the cognitive processes underlying the knowledge-based control. Klein (1989), however, complements the SRK model, as it is specified when looking for an appropriate action based on mental simulation is stopped, i.e., when a satisficing one has been identified (Simon, 1955). In contrast to the skill-based and knowledge-based behavior, no clear counterpart is at hand for the rule-based behavior. For the analytical model of decision making, the actor still mentally simulates different courses of action, which is, however, no longer necessary when the rule-based level of control applies according to Rasmussen's theoretical specifications (1983, 1986, 1990). Hence, it is assumed that the analytical mode of decision making is applied when the actor has experience in the situation, however, rules have not yet been developed, but thorough mental simulations as required in a totally unknown situation, are no longer necessary. This confirms the, in Section 5.3 made assumption that there is a continuum between analysis and intuition, which has been cut in different slices from various researchers.

5.7. Human Adaptation Process of Information Acquisition

Based on the, in Sections 5.1 – 5.6 introduced theories and their described interrelationships, a continuum regarding the course of an adaptation process to a new situation is proposed based on the required information processing demands, as are cognitive processes underlying this continuum.

5.7.1. Description of the Adaptation Process Regarding Information Acquisition

In the Sections 5.1 – 5.6, different modes of information acquisition have been discussed and put in relationship with each other. While the theories described at the beginning (mainly Section 5.1 and Section 5.2) dealt with the mode "perception", the theories presented in later chapters (especially Sections 5.5 and 5.6) focused on higher cognitive processes such as decision making as ways of deciding how to react on given situations. As a variable determining which mode of information acquisition is applied, the familiarity of the situation at hand has been introduced. As the discussions and the highlighted interrelationship between these theories illustrated, the separation between perception and higher cognitive information processing is only an artificial one. Instead, there is a continuous process of information acquisition requiring different levels of information processing, which is mediated by the familiarity of the individual to his/her environment (see Figure 9).

Direct perception (Gibson, 1979, see Section 5.1) and perceptual processing (Kirlik, 1995, see Section 5.4) mark the starting point of this continuous process: The information uniquely specifying an affordance in a given situation is perceived without the need for information processing (i.e., achievement is optimal, vicarious mediation equals vicarious functioning). The observer is to a maximum degree adjusted to his/her environment. Choosing the required activity in order to achieve the goal is according the skill-based level of cognitive control (Rasmussen, 1983, 1986, 1990) only mediated by the perceptual-motor system, which initiates the required movements based on the patterns of the perceived cues or the information in the environment. This skill-based behavior is judged as less adapted, as it still requires some kind of information processing in order to fine-tuning of behavior and to anticipate future events. The same is the case regarding the simple match (Klein, 1989): Situation assessment does still take place. Direct perception, in contrast, does no longer need such cognitive processes to choose and implement the optimal behavior.

For an observer, who is not fully familiar with the situation in question, the information in the environment does not uniquely specify an activity, so that even higher cognitive processes are required in order to decide on the behavior, which will most likely result in the desired outcome. Brunswik (1957 and see Section 5.2) investigated probabilistic perception, that takes place, when not all relevant information are available to the observer (i.e., higher cognitive activities are involved compared to what is proposed by direct perception), and on the other hand thinking with cognitively only little demanding tasks. These two processes are also proposed by the cognitive continuum theory (see Section 5.3.1), but termed *intuition* and *analysis*. Besides, a continuum is proposed in between these two end points, i.e., the quasi-rational processes.

Quasirational processes are especially the rule-based control of behavior (Rasmussen, 1983, 1986, 1990 and see Section 5.5) and the analytical mode of decision making (Klein, 1989, see Section 5.6), whereas the latter requires more information processing. This is the case, as Klein proposes, that the analytical mode of decision making still requires mental simulation of the possible courses of action. However, when the rule-based control of behavior takes place, the course of action is determined and only requires minor modifications.

When the situation is unknown and no rules available to be applied to decide on appropriate behavior, the recognition-based mode of decision making (Klein, 1989, Section 5.6) specifies a thorough situation assessment. Based on situation assessment, related recognition and mental simulation appropriate actions are chosen.

The knowledge-based control of behavior (Rasmussen, 1983, 1986, 1990) requires more information processing: It takes place, when problem-solving behavior is required and the situation is totally new to the observer.

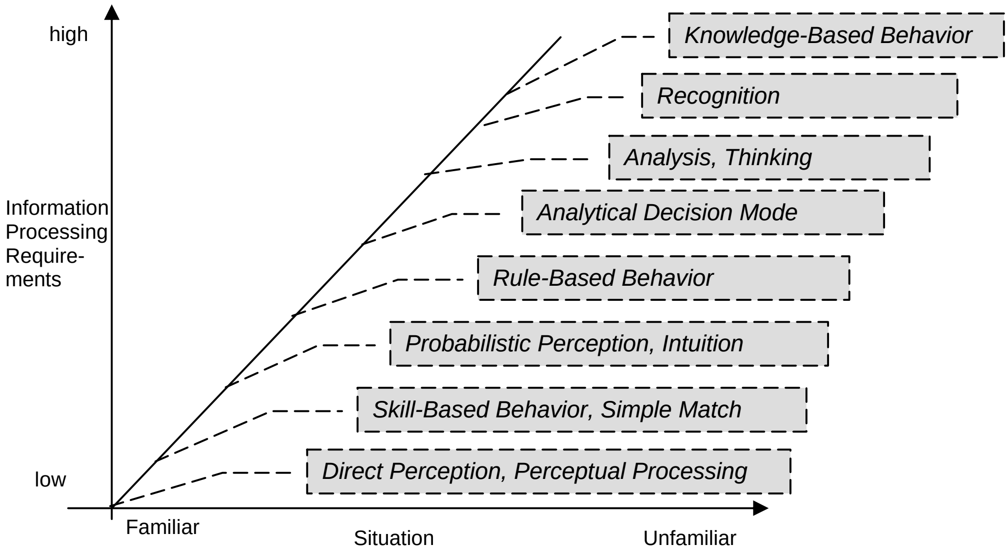


Figure 9. Relationship of the novelty of a situation, the information processing requirements and the interrelationship of the discussed theories (see Sections 5.1 to 5.6) on the proposed continuum.

5.7.2. Cognitive Processes Underlying the Adaptation Regarding Information Acquisition

With the progress of the adaptation process, the information from the environment in the optic array takes a different form – as already indicated by Brunswik (1957) and Rasmussen (1983, 1986, 1990). Although it is assumed that this process is a continuous one, three artificial phases can be distinguished:

At the beginning of the adaptation process the information is unstructured and without meaning. When confronted with such a totally new and unknown situation, the available, sensory information is used to build an internal model of the external reality required for problem solving and deciding on the most successful action. This sensory information informs about objects available in the environment and is used to build logical relationships between these proximal variables. In order to be a successful mean for selecting an appropriate action, information on the functional purpose, the abstraction function, the generalized function, the physical functions and the physical form are required, as stated by the abstraction hierarchy (Rasmussen, 1979, 1983, 1985, 1986). As the proximal variables perceived also appear in other representations, a causal texture evolves (see Section 5.2.2). The resulting equivocality is reduced by reasoning and experience with the situation (see Section 7.2).

As soon as the mental representation is formulated, potential plans are worked out and their effects tested based on mental simulations making use of the internal representation, as described by the complex RPD strategy (Klein, 1989 and see Section 5.6) and the decision ladder (Rasmussen, 1986 and see Section 5.5). In case of high importance of achieving the goal successfully, the complete set of alternative plans is worked out and analyzed. Then, a satisficing solution (Simon, 1955) is not considered sufficient. In case, motivation is less strong and the consequences of possible errors not catastrophic, the process of analyzing the set of potential actions, is stopped after a satisfying one has been found (see Klein, 1993 and Section 5.6).

This first phase of the information acquisition, during which the cognitive work load is high, is referred to as knowledge-based, parallel to Rasmussen (1983, 1986, 1990 and see also Section 5.5.).

This relationship between behavioral plans, their success and the emerging internal representation is getting stronger so that, the mental simulations step into the background. Cues have been determined, which are anchors to direct links to a rule guiding the actions. The second phase of the adaptation process has been reached. Proximal cues are no longer perceived, instead, local variables or cues are acquired as an anchor to a suitable, goal-directed rule (see Section 5.2).

When the adaptation process continues, this link between the situation and successful activities gets stronger. It is no longer an anchor indicating the action; instead, the situation (i.e., the distal variable) with all influencing variables is perceived and directly indicates the most successful action (see Section 5.1.). The internal representation has been built successfully and information processing is no longer necessary. The affordance representing the direct link between the situation and the activity was originally hidden and is now – because of the adaptation process

– perceptible (see Gaver, 1991 or Section 5.1.2.). Skill-based behavior takes place (Rasmussen, 1983, 1986, 1990) and cognitive control of behavior low, as is conscious awareness (Hammond, Hamm, Grassia, & Pearson, 1987). Fluid sensory-motor behavior takes place.

6. Human Behavior: Operations and Activities

In the following, theories classifying different modes of human behavior are introduced (see Sections 6.1 – 6.3). As a mediating variable, an adaptation process to a situation is discussed determining the mode of behavior applied by the actor. An overview over the proposed continuum of adaptation and underlying cognitive processes is given in Section 6.4, which is further put in relation to the one proposed for information acquisition (see Section 5.7).

6.1. Exploratory Behavior and Performatory Activities

6.1.1. Ecological Theory of Direct Action

Gibson (1966) distinguishes between exploratory and performatory activities: *Performatory activities* are realizations of affordances provided by the environment (see Section 5.1). *Exploratory activities* refer to the activities of the perceptual system to actively seek information (Gibson, 1962). Hence, exploratory activities have informational value for the actor (Flach & Warren, 1995). For example, a hand free to explore objects better allows for discriminating objects as is possible with a hand that is constrained.

Besides the interface guidelines (see Section 6.1.2), a body of empirical research has advanced out of Gibson's ecological theory of action in different domains:

Shaw, Flascher, and Kadar (1995) aimed at defining guidelines for safe and efficient travel for wheelchair users and at defining measures allowing evaluating functional architectures. To analyze how wheelchair users perceptually select fields of comfortable travel, two studies were conducted: During the first study (see also Flascher & Shaw, 1989 and Flascher, Shaw, Carello, & Owen, 1989), each participant ($N = 4$) had to roll with his/her wheelchair along a line parallel to eleven apertures 14 times. They were asked to stop at the aperture which is the smallest they can possibly get through with their wheelchair and then drive through this aperture as fast as they could. A passablity number of 1.18 resulted, which is the ratio between wheelchair scales and environmental structures. In the second study (see also Flascher & Carello, 1990) 14 participants were asked about the minimum width of an aperture they could possibly drive through with a wheelchair or simply walk through. The passability number for wheelchair users reached 1.22 and the one for walking participants 1.12, which were significantly different from each other $F(1, 13) = 8.56$, $p < .05$). The participants of both studies had no experience with driving a wheelchair.

In a series of studies, Zapf (1989) analyzed the capability to judge on another individual's affordances on the example of reaching capabilities. The results demonstrated that (1) the persons are generally speaking better at judging their own affordances than other persons' affordances, that (2) the greater the action-related differences between the judges and the other persons, the less accurate are the judgments on the affordances, and that (3) experience in judging about another person's affordances increased the accuracy of the judgments.

6.1.2. Applications of the Ecological Theory of Direct Action in the Field of Human-Computer Interaction

The concept of affordances has been applied to derive practical guidelines for designing interfaces (see e.g., Baerentsen, 2000; Benett & Flach, 1992). For example, direct manipulation displays (Bennett & Flach, 1992; Flach & Bennett, 1992; Vicente & Rasmussen, 1990) try to make affordances visible by using a display which allows directly manipulating reality, so that the tool steps into the background. From a theoretical point of view, direct manipulation interfaces are further based on the syntactic-semantic model of Shneiderman (1983) and the gulfs of evaluation and execution of Hutchins, Hollan, and Norman (1986).

6.1.3. Theoretical Relevance of Exploratory Behavior and Performatory Activities in the Context of Human Behavior

A wheelchair enhances or restores functionally defined operation capabilities of the person in need and allows him/her to perform activities which otherwise could not be realized (see e.g., Flascher & Shaw, 1989). The tool, thus, augments the range of affordances of the person. As such, it belongs to the person, but can also be interpreted as being associated with the environment, as it invites certain actions from the user. This demonstrates the concept of Gibson (1979) of not analyzing the actor and his/her environment separately but the complete ecosystem. However, only extending the set of affordances of the wheelchair user is not sufficient. The affordances need to be made perceptible (Gaver, 1991 and see Section 5.1) by acquiring which information in the environment specifies this extended set of affordances. Hence, in terms of Gibson, pattern discrimination is needed (see Section 5.1). This reasoning gives an explanation of why wheelchair users need to learn to use their tool appropriately to support their daily activities best (see Section 1).

Gibson's ecological theory of direct action (1979) differentiates two classes of human behavior: Exploratory activities take place, when not sufficient information is available specifying an affordance, which is the case, when an environment is not familiar (see Section 5.7). Hence, exploratory activities aim at gathering information about the environment, and are, as such important for specifying the internal representation of the environment. Some properties of the environment cannot be perceived and need to be explored. With the development of the internal representation, the necessity to execute exploratory activities decreases and the number of performatory activities increases, which are realizations of affordances.

6.2. Operations, Actions, and Activities

6.2.1. Activity Theory

A group of Russian psychologists (Lev Semyonovish Vygotsky, Alexander Romanovich Luria, and Alexei Leontyev) founded activity theory in the 1920s and 1930s. The principle of unity and inseparability of consciousness and activity is its basic component stating that the human mind can only be understood in the context of meaningful, goal-oriented, and socially determined interaction between the actors and their environment (Vygotsky, 1978).

The basic unit of analysis is the activity, which is structured hierarchically (Leontyev, 1978, and see Table 4):

- Activities are reactions on human motives, which explain why something takes place (Kuutti, 1996).
- Actions are conscious components of activities and are guided by a goal. The goal answers the question of what takes place (Kuutti, 1996; Nardi, 1996).
- Operations explain how actions are implemented to achieve the goals (Kuutti, 1996). With practice, operations become routinized and unconscious.

Table 4

Different Aspects of the Activity Structure (Adapted From Albrechtsen, Andersen, Bodker, & Pejtersen, 2006)

Type of activity	Directed at	Analysis
Activity	Motives	Why does something take place?
Action	Goals	What takes place?
Operation	Conditions	How is it carried out?

With practice the role of activities, actions, and operations changes (Davydov, Zinchenko, & Talyzina, 1983; Kuutti, 1996): An activity looses its motive and becomes an action; an action becomes an operation as the planning and decision making component fades away. The original motive of the activity turns into a goal of the action. The execution of operations becomes more fluent and consciousness might fade (Kuutti, 1996). According to Leontyev (1978), all operations can be automated and, thus, become unconscious.

Crucial prerequisites for an activity turning into an operation were summarized by Bodker (1991):

- Practical experience is essential for learning.
- Actions with an abstract goal can better be acquired with physical objects instead of representations of these objects.

- Generalization takes place. Operations are first situation-specific but can - with practice - be generalized to new conditions.
- The novice needs to plan each activity, each action, and each operation. With practice, this need diminishes and special operations can be skipped due to the acquired knowledge about their conditions and results.
- The pace at which can be learnt, depends on the artifact, or more specifically, on how much the learner can rely on the generality of the operations, on the type of education, and on whether experience can be made use of.

Another basic principle of activity theory is the mediation of human activity by tools (Engeström, 1987; Kaptelinin & Nardi, 1997; Kuutti, 1996): Tools are an important mean to satisfy a human motive underlying an activity. While an activity turns into an operation, the role of the used tool does also change. Kaptelinin (1996) distinguishes three phases: The initial phase is characterized by equal performance with and without a tool, because the tool is not yet mastered to result in increased performance. The intermediate stage is achieved when tool-aided performance exceeds performance without the tool. The last or final stage is characterized by a total internalization of the tool, so that the external tool is no longer required. This stage does only hold for tools, which can totally be internalized.

6.2.2. Application of Activity Theory in the Field of Human-Computer Interaction

Activity theory has been introduced to the field of human-computer/machine interaction by Bodker (1989, 1991; for an overview see e.g., Nardi, 1996). The computer or the machine is interpreted by activity theorists as a tool mediating the interaction of the human being with his/her environment (Kaptelinin, 1996). However, clear guidelines for human-computer/technology interaction have neither been deduced nor studies conducted to test the practical value of the activity theory.

6.2.3. Theoretical Relevance of Operations, Actions, and Activities in the Context of Human Behavior

Activity theorists propagate to focus on the behavior and distinguish activities, actions, and operations (e.g., Albrechtsen, Andersen, Bodker, & Pejtersen, 2006). First, the hierarchy itself, second the changes of the activity structure give important insights regarding the adaptation process of the human being to his/her environment. In a new situation, the person initiates planning of actions, which describe how the motive of the activity can be satisfied. The more detailed planning and the consideration of conditions, i.e., how operations are carried out take place as well. With exposure to the situation, with experience and after sufficient information has been gathered and processed, the motive fades, the planning component is reduced and only conditions need to be considered. Actions take place. In a last step, planning is redundant; the former activity is now an operation. Information processing is no longer necessary. For example, playing a piece of music with the piano is initially an activity and turns, with experience, into an operation which hardly requires the musician's attention.

The performatory actions (Gibson, 1979 and see Section 6.1), which take place when a situation is unfamiliar, are conducted in order to gain knowledge about the impact of the operations and actions while planning how to execute them. The necessity to execute them, however, decreases when an activity turns into an operation. This is why the exploratory actions are, in the following, termed *exploratory activities*.

6.3. Creative Expressive Actions

6.3.1. Situated Actions

Suchman (1987) distinguishes between two types of activities: The *instrumental goal directed activities* describe actions derived from the abstract analytical way of thinking. The plan, which guides actions, is derived from universal principles and is independent from the particular situation. *Creative, expressive actions* clearly define the objective from the outset; however, the actual course is dependent on unique circumstances and situations, which cannot be anticipated in advance by the actor. The actions are ad hoc. Suchman argues that the type of actions that takes place depends on the degree of expertise: Instrumental, goal directed activities are pursued by novices; whereas creative, expressive activities are performed by experts. However, especially rational, situation-independent behavior ignores that the circumstances of the actions can never be fully anticipated and continuously change, so that behavior can never be fully independent from situations. Suchman terms these types of actions *situated.*

Suchman's (1987) theoretical advancements were based on a study about an expert help system for a photocopy machine, which was developed by Richard Fikes at the Xerox Palo Alto Research Center in 1982-1983. The expert help system was supposed to provide timely and relevant information to the user about how to operate the copy machine. This information was provided to the user in a step-wise order, wherein each next instruction was evoked by the user's successful implementation of the last information. The underlying rational was that the course of the user's actions serves as an enactment of a plan for doing the job (i.e., planned action), as the scope of possible goals was limited due to the purpose of the machine's existence. In order to define this plan, the user was asked a series of questions about the state of the original document and the desired copies. Depending on the answers, a job specification was defined, with which plan was associated. This plan was then used to interpret the user's actions and to give an appropriate next instruction.

To test the expert help system, first-time users were filmed when using the copy machine. Suchman (1987) compared the users' actions which were available/not available to the machine, and the machine's effects, which were available to the user and the underlying design rationale. The results showed first that the users' behavior was ad hoc and incremental. A plan was not used. Second, communication problem occurred because the machine was only partially aware of the situation of the user's inquiry and goal (see also Jipp & Badreddin, 2006). According to Suchman the system failed, as human behavior is situated and not planned.

6.3.2. Creative Expressive Actions in the Context of Human Behavior

Suchman's concept of situated actions (1987) is based on the study testing the photocopy machine, which design rational originated from the assumption that users follow a plan. The study's participants were first-time users unfamiliar with the system, so that only the activity "operating the photocopy machine" was analyzed (see Leontyev, 1978; Section 6.2). In that phase of the adaptation process, however, a successful plan operating the machine cannot be assumed since an internal representation necessary for formulating such a plan has not yet been elaborated. As described in Section 6.2.3, if no plans are available, which allow achieving the given goal, exploratory activities take place. These exploratory activities support building an internal representation of the situation, on which basis a plan can be worked out and realized. These exploratory activities resemble the creative, expressive actions, Suchman (1987) described and which were observed in her study when analyzing the behavior of the first time users of the photocopy machine.

With experience with the situation, an internal representation is available, which also specifies the relevant conditions for the success of the operation "operating the photocopy machine" and how an adaptation of an operation to given conditions is required. Hence, when the person is fully adjusted to a situation, operations are available for all conditions of the environment requiring a different way of achieving an action. The actor executes instrumental operations. In accordance with Suchman (1987), it is expected that every behavior is situated; however, in contrast, it is assumed that creative, expressive activities are performed by novices and instrumental operations by experts.

6.4. Human Behavior: Adaptation Processes

6.4.1. Description of the Adaptation Process Regarding Human Behavior

The adaptation process changes human behavior. This process is continuous (see Figure 10), as is the one proposed regarding the information acquisition (see Section 5.7). The discussions of Gibson's (1979) ecological theory of direct action, of the activity theory (e.g., Leontyev, 1978) and of Suchman's (1987) concept of situated actions demonstrated, that behavior and its purpose change with the adaptation to an environment: While, initially, when confronted with a new situation, no patterns of movements are at hand to satisfy a motive, creative behavior is executed, which will give the actor valuable information about the environment. This behavior is described by Suchman as creative, expressive actions and by Gibson as exploratory. The execution of such expressive behavior provides the actor with information, which will be used to build an internal representation of the map and to complement other sensory information (see also Section 5.7). Based on such an internal model, ways of satisfying the motive can be worked out. Their effects will be simulated mentally (see also Section 5.7) and the supposedly most promising one realized. The feedback from the environment and the achieved result(s) will again allow further elaborating the internal representation of the situation. The requirement to process information is maximum. With continuing exposure and experience, this activity will loose its motive and an action results (see e.g., Davydov, Zinchenko, & Talyzina, 1983; Kuutti, 1996). An explicit goal is stated, which the action aims at achieving. With further practice, the focus is put on how the behavior can best be succeeded, so that the action turns into an operation. Consciousness of the movements fades, available affordances are realized. Performatory behavior takes place (Gibson, 1979).

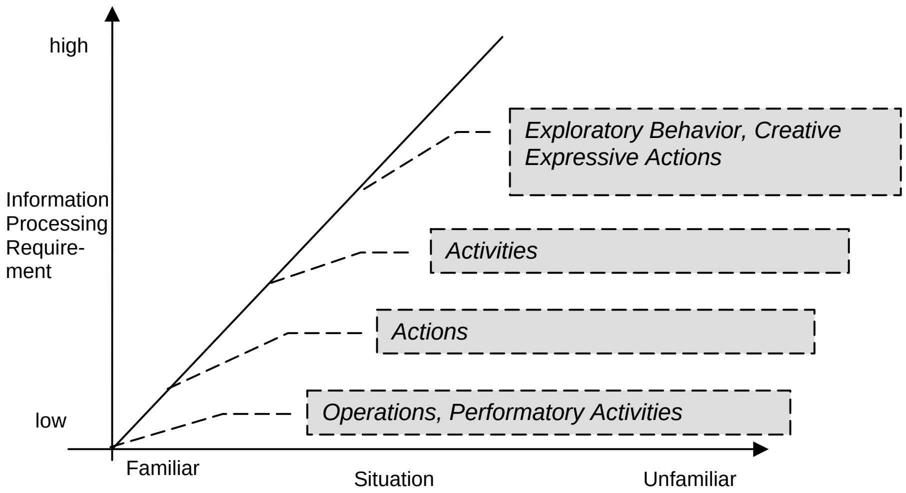


Figure 10. Relationship between the familiarity of a situation, the information processing requirements and the type of behavior executed.

6.4.2. Relationship Between the Adaptation Processes Regarding Information Acquisition and Human Behavior

The structural change of human behavior runs parallel with the already described change of the structure of perception (see Section 5.7). Similar cognitive processes underlie both, the change of the human behavior and the one of the information acquisition. At the beginning of the adaptation process, local perceptual variables are perceived, which are, as in the first phase of the adaptation process described regarding information acquisition used for reasoning about a distant variable, i.e., the situation. These proximal variables point to operations. These operations has to be reasoned about in order to define an activity which allows satisfying the existent motive. An internal representation is worked out, based on which the reasoning for judging on the situation and for defining an appropriate activity is enabled. With experience, the internal representation gets more elaborated and the reasoning component fades: anchors, informal cues are perceived, which point to rules and then, the situation is sensed directly specifying an activity. The adaptation process has come to an end, as soon as direct perception and *direct activities* take place. The term direct activity refers to an operation, which was, initially an activity as defined, e.g., by Leontyev (1978).

7. Determinants of the Adaptation Process Regarding Information Acquisition and Human Behavior

As described in Section 4, situation adaptation is to some extent related to skill acquisition. In order to define variables influencing the adaptation to a new situation regarding information acquisition and human behavior, the research about the individual differences determining differences in skill acquisition is introduced in the following. The results are discussed and related to the previously described adaptation processes regarding information acquisition and human behavior.

7.1. Skill Acquisition and its Determinants

7.1.1. Ackerman's Integrative Skill Acquisition Theory (1988)

Ackerman's skill acquisition theory (1988) is based on the research conducted by Anderson (1982, 1983), Fitts (1964), Fitts and Posner (1967), Fleishman (1972a), Fleishman and Quaintance (1984) as well as Schneider and Shiffrin (1977; Shiffrin & Schneider, 1977). As do Fitts and Fitts and Posner, Ackerman distinguishes three phases of skill acquisition:

- The first phase is characterized by a relatively strong demand on the cognitive-attentional system, so that performance is slow and error prone. Ackerman explains this phase as the one in which productions are formulated and tested (see Anderson, 1982). Attention is required to thoroughly understand the task in question. With consistent practice, performance gets faster (see Schneider & Shiffrin, 1977) and attentional demands are reduced (see Fisk & Schneider, 1983).

- During the second phase, the productions are fine-tuned to accurately perform the task in question and the successful one strengthened.
- Finally, performance is fast and accurate. The task is automated and can be completed without much attention (see Schneider & Fisk, 1982).

Performance in each of these three phases of skill acquisition is determined by abilities, namely by general intelligence, perceptual speed ability, and psychomotor abilities (Ackerman, 1988).

General intelligence was defined in accordance with Humphreys (1979), as the ability to acquire, store, retrieve, combine, compare information and use it in new, other contexts. Hence, general intelligence is the ability to process information non-specifically.

Perceptual speed refers to the speed with which simple production systems can be implemented and compiled to solve very easy cognitive test items (see e.g., Marshalek, Lohman, & Snow, 1983; Werdelin & Sternberg, 1969). The key is the speed with which symbols can be consistently encoded and compared (Ackerman, 1988).

Psychomotor abilities refer to the speed and accuracy of motor responses to test items without information processing demands (Ackerman, 1990). Some psychomotor tests require a limited amount of information processing; however, the tests are characterized by the fact that the participants are familiar with the kind of responses, which need to be made.

Ackerman (1988) proposes that general intelligence determines initial performance on a task with new information processing demands (see Figure 11). The impact of general intelligence depends on task complexity (see Section also 5.3), but also e.g., on the adequacy of instructions (see Ackerman, 1988). The influence of general intelligence on performance diminishes, when production systems have been formulated for the skill in question. This relationship between ability and performance has empirically been supported by e.g., Ackerman (1986, 1988), Kyllonen (1987), or Sternberg (1977).

The learner proceeds to the second phase of the skill acquisition process, when an adequate cognitive representation of the task has been built. Then, performance depends less on general intelligence, but more on psychosensoric abilities. It is required to fine-tune and compile the developed production systems, which equals the definition of the abilities underlying psychosensoric abilities. Sequences of cognitive and motor processes get integrated, productions adapted for successful task performance (Ackerman, 1990).

With further practice the impact of psychosensoric abilities on performance decreases while psychomotor abilities determine performance. In this third phase of the skill acquisition process, the proceduralisation of the skill is finished and does no longer limit performance; instead it is restricted by the psychomotor speed and accuracy (Ackerman, 1990). The last phase is only reached if an automization of the task can be achieved (Ackerman, 1988).

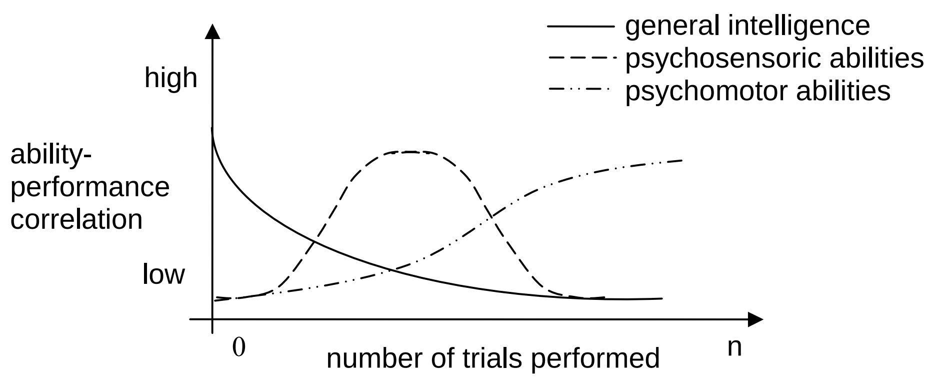


Figure 11. Ability/performance correlations during skill acquisition (adapted from Ackerman, 1988).

The hypotheses derived from Ackerman’s (1988) skill acquisition theory have been validated various times in various settings (see e.g., Ackerman, 1989, 1990; 1992; Farrell & McDaniel, 2001; Jipp, Pott, Wagner, Badreddin, & Wittmann, 2004; Kanfer & Ackerman, 1989a; Schmidt, Hunter, Outerbridge, & Goff, 1988). Two studies are explained as examples:

Ackerman (1988) tested 334 participants with two variants of a nine-choice discrimination reaction time task. The initial variant required hardly any information processing: Single digits from 0 to 9 were presented to the participants who had to press the corresponding key of the keyboard. The second version required the participants to encode and translate a two-letter abbreviation to derive the number of the key which should be pressed. Fifteen sessions with 60 trials each were performed. The results regarding the initial version showed that perceptual speed was highly correlated with performance and showed attenuation with practice with $R_{cub}^2 = .88$ (F $(3, 2) = 5.11$, $p < .05$) and that general intelligence showed stable correlations with performance $R_{lin}^2 = .05$ (F $(1, 4) > 1$). During the second version, the influence of perceptual speed and general abilities was revised due to the added information processing component: The impact of perceptual speed declined ($R_{lin}^2 = .15$, F $(1, 7)$ $= 1.31$, $p < .05$) and the one of general intelligence gained influence ($R_{cub}^2 = .64$, F $(3, 5) = 3.00$, $p < .05$).

Eyring, Steele Johnson, and Francis (1993) investigated the impact of the reasoning ability on performance. For this purpose, 115 students performed a simulation of an air-traffic control task (Kanfer & Ackerman, 1989b). Their cognitive abilities were measured using the Wonderlic Personnel Test, Form 1 (Wonderlic, 1983). In accordance with Ackerman's (1988) theory, the cognitive abilities significantly ($p < .05$) predicted the learning-rate constant calculated by the authors. Hence, students with higher cognitive abilities gained better performance results and proceeded to the next phase of the skill acquisition process faster.

7.1.2. Variables Influencing the Prototypical Skill Acquisition Process

As the description of Ackerman's skill acquisition theory (1988) has demonstrated, the prototypical skill acquisition process is determined by a variety of variables (see Figure 12). These variables can be classified as related to the participant or to the task in question.

The variables associated to the learner influencing skill acquisition are the cognitive abilities, motivation, experience, and gender. The first two are subsumed under the term *psychological*; the last two are termed *non-psychological*.

The cognitive abilities, i.e., general intelligence, psychosensoric speed and psychomotor abilities, and their relevance regarding skill acquisition have already been described in the Section 7.1.1.

Motivation has been defined by Heckhausen (1991) as a “global concept for a variety of processes and effects whose common core is the realization that an organism selects a particular behavior because of expected consequences, and then implement it with some measures of energy, along a particular path” (p. 9). The impact of motivation on skill acquisition is described by the integrated resource allocation model (Kanfer & Ackerman, 1989a), which separates the amount of cognitive/attentional resources allocated to task-relevant and task-irrelevant actions. Hence, lacking motivation will result in little cognitive/attentional resources devoted to the adaptation process, so that especially its first phase process is hindered.

Experience can influence the process of acquisition (Holding, 1991): Transfer takes place, if the skill specificity of the current task is low (Ackerman, 1990). Skill specificity is defined as the number of components of either declarative or procedural knowledge the two tasks in question have in common (see also Thorndike & Woodworth, 1901). The level of transfer or influence on the adaptation process depends (1) on the stage of the adaptation process of the first task and (2) on the strength of the skill that was acquired first (Ackerman, 1990). Transfer is weakened, if the first task has never reached the final stage of the skill acquisition process, and strengthened, if the skill has been strengthened a couple of times with successful practice trials. In case transfer takes place, it has to be distinguished between positive and negative transfer (Ackerman, 1989). Positive transfer results, when the productions required for executing the activities do support each other; negative transfer takes place, when the productions required for executing the two activities contradict each other.

Gender differences have been found by various researchers especially regarding figural abilities such as spatial perception and mental rotation (see e.g., Linn & Petersen, 1985; Maccoby & Jacklin, 1974; Sanders, Soares, & D’Aquila, 1982). Hence, if the task in question requires figural abilities to build the production system in the first phase of the skill acquisition process, gender differences might influence the acquisition process.

Two task-related variables influence the adaptation process: task consistency and task complexity. Task complexity influences the initial variability and the rate of attenuation with practice between learners (Ackerman, 1988). Complexity is defined based on the situation's memory load, the number of response choices, the number of intermediate results, etc. (see also Hammond, Hamm, Grassia, & Pearson, 1987). Changes in task complexity influence the amount of attention required to perform the task and increase the impact of general abilities and perceptual speed (Ackerman, 1988, see also Section 5.3.2).

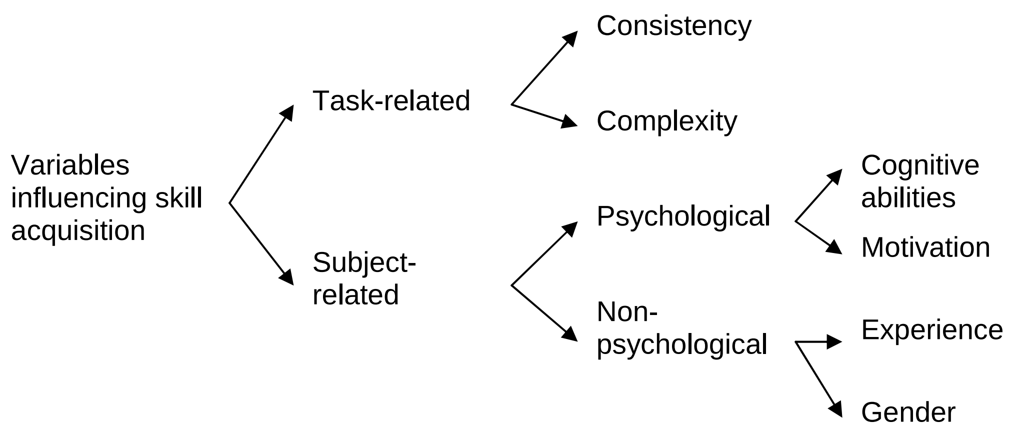


Figure 12. Variables influencing the prototypical way of skill acquisition as described by Ackerman (1988) (adapted from Jipp, 2003).

A consistent task requires consistent information processing, i.e., there is complete certainty about which responses are required for which stimuli (Schneider & Shiffrin, 1977). Inconsistencies have a great impact on skill acquisition, although they do not influence the initial task performance (Ackerman, 1988). However, with practice, the inconsistencies make the learner build new productions again and again, so that the task always remains cognitively demanding and the learner never proceeds to the second phase of the skill acquisition process (see e.g., Fisk & Schneider, 1983; Nissen & Bullemer, 1987; Schneider & Fisk, 1982). This also explains why performance difference between learners does not diminish for inconsistent tasks (Ackerman, 1986, 1987). If a task is consistent, performance variability between persons does decrease (see e.g., Shiffrin & Schneider, 1977). Hence, for inconsistent tasks, skill acquisition does not take place.

7.1.3. Theoretical Relevance of Skill Acquisition and its Determinants in the Context of Situation Adaptation

Ackerman (1988) states that his theory of skill acquisition does only hold for tasks requiring motor skills, which he defines in accordance with Adams (1987) as a “wide behavioral domain”, which is “learned”, and which “goal attainment is importantly dependent upon motor behavior” (p. 7). However, nearly, if not all human behavior depends on motor behavior, as is proposed by the cognitive architectures (see e.g., Anderson, 1990). While for healthy individuals, the motor behavior required to realize “non-motor” skills might not exhibit individual differences determining performance differences and skill acquisition, this might be different for participants with (severe) motor disabilities.

7.2. Situation Adaptation and its Determinants

As Ackerman’s (1988) skill acquisition theory demonstrates, task characteristics, relevant abilities of the human being and related individual differences between learners have a clear impact on the course of skill acquisition. Due to the, in Section 4 described similarities between skill acquisition and situation adaptation and the description of the adaptation process regarding information acquisition and human behavior (see Sections 5.7 and 6.4), it is expected that the situation and the actor’s relevant abilities influence the adaptation process and that individual differences regarding these abilities determine different courses of adaptation. The exact relationships and an explanation are introduced in the following.

7.2.1. Influence of the Situation’s Characteristics

Depending on the situation and on the observer, i.e., the subjective and objective task characteristics (see Figure 5 and Section 5.3.2), the, in Figure 9 and Figure 10 depicted curve can vary: In some environments, an adaptation process is hardly possible, in others, an adaptation process is nearly not necessary. The, in

Section 5.3.2 and in Section 7.1 introduced variables related to the situation influencing this process are complexity and consistency.

If an environment changes continuously in an unpredictable way and is, as such, inconsistent, an adaptation process cannot take place. Instead, the information processing requirements will always stay at a high level. An internal representation of the environment cannot be built, as the conditions always change and there is no consistent mapping between the situation and an optimal activity. Hence, direct perception and direct activities cannot be achieved. However, the consistency of a situation cannot be considered a dichotomy. Instead, Ackerman (1989) distinguishes two types of inconsistencies: within and between task components. Task components refer to different, independent parts from the task. A similar distinction can be made regarding situation adaptation: A subset from the internal representation to be built can be consistent, while another subset changes continuously. The first one allows the formation of direct activity/perception, the latter one does not. Summarizing, a completely consistent task, allows full situation adaptation (if the abilities are developed in the required degree), a completely inconsistent task does not allow any adaptation for all participants, and a continuum in between these two extremes is assumed. Whether and to what extent adaptation is possible, is indicated by the intercept of the curve (see Figure 13).

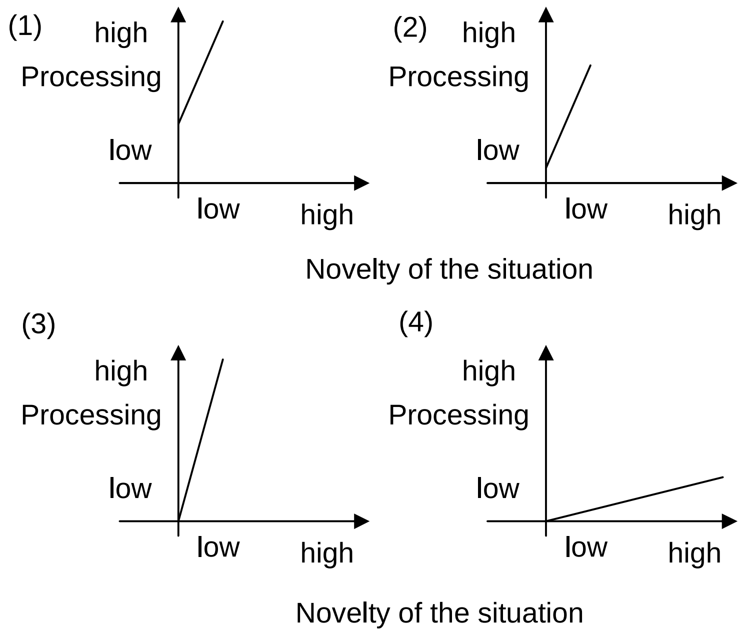


Figure 13. Relationship between the novelty of a situation and the information processing requirements for (1) a less consistent and (2) a more consistent environment as well as for (3) a relatively easy-structured and (4) a more complex environment.

The slope of the curve (see Figure 13) demonstrates how complex an environment is (for a definition of complexity, see Section 5.3.1 and 7.1.1). As proposed by Hammond, Hamm, Grassia, and Pearson (1987), the environment can determine the level of cognitive control applied: An easy-structured environment requires hardly any information processing and adaptation proceeds quickly, even if the environment is not familiar. Hence, the slope is steep.

7.2.2. Influence of Abilities and Individual Differences

The, with the adaptation proposed changes of information acquisition and human behavior (see Sections 5.7 and 6.4) have been described as continuous processes, which have been, based on the underlying cognitive processes artificially cut in three phases.

When confronted with a new situation, an internal representation of the situation is built. For this purpose, proximal cues from the environment are perceived and processed, based on which an appropriate number and order of operations can be chosen to satisfy a motive. Exploratory behavior supports the information acquisition. Hence, the need for information processing is high: The acquired information needs to be compared with already stored information, other information must be retrieved from memory, judgments and decisions about the perceived cues need to be made. This internal representation allows mentally simulating the effects of sets of operations. On their outcome, plans are specified with chances for success. Based on increasing practical experience with the situation, the information in the environment specifying which plan should be executed can be determined (i.e., anchors). With exposure and practical experience in the situation, this high need for information processing decreases. What gains importance, is, the ability to compare the perceived information with what is saved in memory. The information processing demands decrease, until the observer can directly act upon a perceived situation. Performance is now limited by motor abilities such as speed and/or accuracy.

The level of the psychomotor abilities also plays a role in defining the best way to manage the situation, i.e., the definition of the way of how to execute the operations. Due to individual differences in psychomotor abilities, for some participants, another way of executing operations might be the better choice. Hence, the way a person will manage a situation is highly dependent on the person's intellectual and motor abilities. Which intellectual and which psychomotor abilities exactly determine the situation adaptation is described in the following.

7.2.2.1. The role of intelligence.

The Berlin Intelligence Structure Model (BIS, Jäger, 1982, see Figure 14) is a hierarchical model of intelligence: General intelligence, at the top level, is composed of two facets, which are categories for factors at the next lower level (Canter, 1985; Guttman, 1954). Jäger (1982) distinguished the facet operations and contents. The latter one subsumes three content abilities (i.e., numerical abilities, verbal abilities, and numerical abilities), which refers to how a person cognitively deals with the different types of contents. The facet operation subsumes what it is that is cognitively done with the given contents. The operations processing capacity, memory, creativity, and perceptual speed have been empirically defined by Jäger. Processing capacity is explained as the ability to solve complex problems (Jäger, Süß, & Beauducel, 1997). According to Jäger (1967) this is the ability to process complex information which includes retrieving, comparing old and new pieces of information and making judgments (see also Humphreys, 1979). Memory tasks demand the participants to memorize pieces of information and retrieve them from short-term memory or recognize them after a short period of time. Creativity refers to the ability to produce a variety of differing ideas controlled by a given item. Last, perceptual speed tasks require a participant to work as fast as possible on simple tasks, with no or only little information processing demands (see also Ackerman, 1988).

The BIS has been validated by a variety of researchers using different statistical methods (e.g., Bucik & Neubauer, 1996; Jäger & Tesch-Römer, 1988;

Kleine & Jäger, 1989; Pfister & Jäger, 1992; Süß, 1996). These studies are based on different populations, different test items and different statistical analyses. Still, they show comparable results and confirm the importance and scientific value of Jäger's (1982) work.

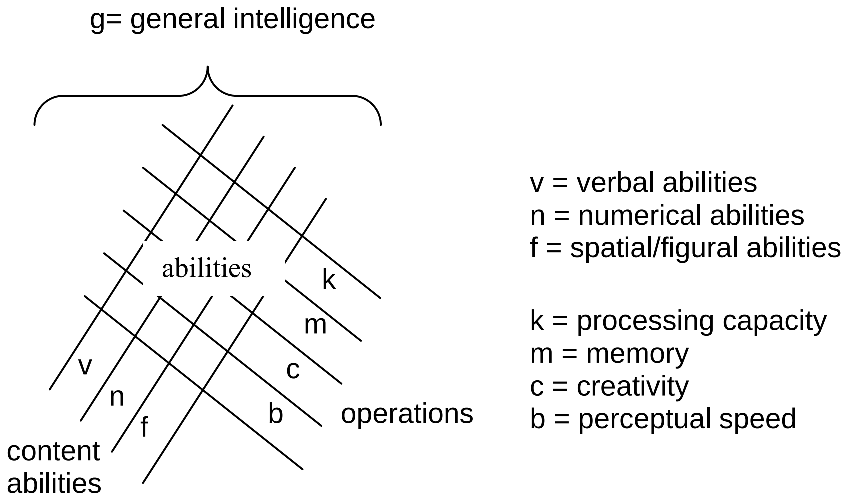


Figure 14. Berlin Intelligence Structure Model (adapted from Jäger, 1982).

As described before, the intelligence factors influence the adaptation regarding information acquisition and human behavior. The cognitive processes proposed involve comparing information, reasoning about the perceived cues, making judgments, which equals the introduced definition of processing capacity. As soon as the internal representation has been built and mental simulations executed, rules are available for successful actions and information specifying the rules. At that stage, the impact of the processing capacity decreases, and the psychosensoric abilities start determining the adaptation process. Now, new information must be compared with already stored information and acted accordingly.

The adaptation process is further influenced by the content abilities, which are addressed by the current situation. More specifically, it will influence building an internal representation about the situation, the mental simulation of potential activities and the definition of plans and according anchors, i.e., all cognitive activities involved when adapting to a new situation and as such, the first and second phase of the adaptation process.

Hence, participants with greater (relevant) intelligence abilities will be able to build the internal representation of the situation quicker (for a study investigating the impact of processing capacity on the pace of skill acquisition, see e.g., Eyring, Steele Johnson, & Francis, 1993), they will perform fewer errors and they will have identified appropriate rules and anchors more quickly. These differences between actors/observers will decrease, as the requirement for information processing decreases (see Figure 15).

Comparing the adaptation processes for different situations, it is to be considered that situations with a different degree of complexity will require a different level of information processing involved. Highly complex situations will demand a higher level of intelligence in order to successfully build the internal representation and to define appropriate rules and anchors (see Figure 15). If the level of intelligence is not sufficient, the adaptation to the situation is not possible.

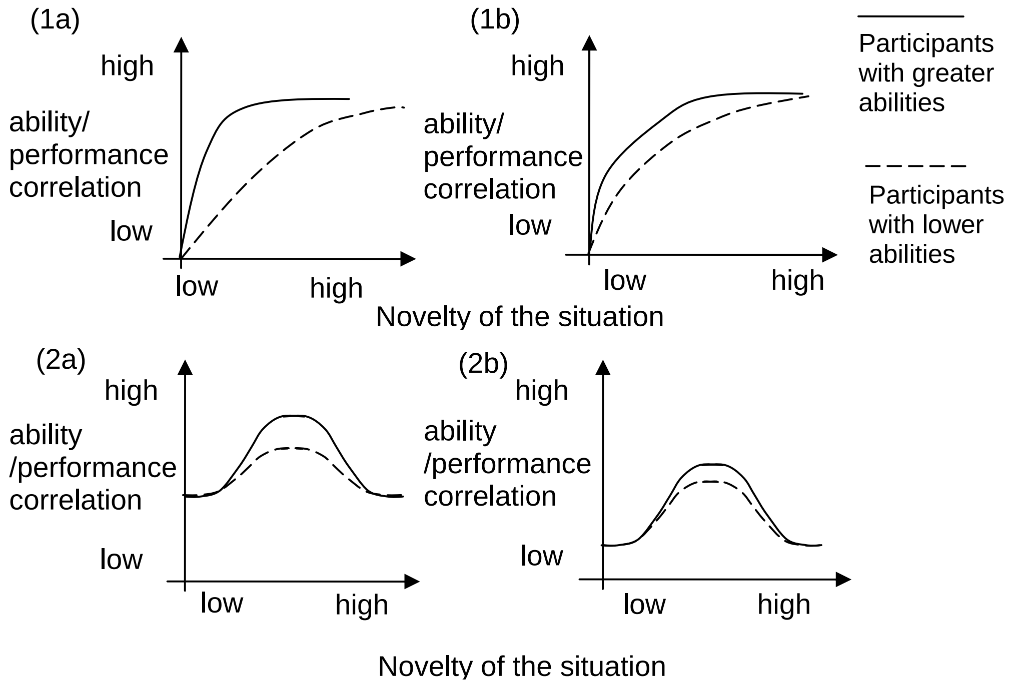


Figure 15. Relationship between the ability/performance correlations of the participants' processing capacity abilities (1) and processing speed abilities (2) and the novelty of the situation for a more complex (a) and less complex (b) situation.

7.2.2.2. The role of psychomotor abilities.

Many researchers investigated the factor-analytic structure of psychomotor abilities. In accordance with Henry's (1968) specificity hypothesis, most of them (see e.g., Bachman, 1961; Drowatzky & Zuccato, 1967; Fleishman & Parker, 1962; Keele & Hawkins, 1982; Lotter, 1960) come to the conclusion that there is no general motor ability but many specific, independent motor skills. Research on the structure of psychomotor abilities was piloted by Fleishman (1954), who defined 12 factors of psychomotor abilities when analyzing the test results of 400 participants, who performed 38 psychomotor tests. These twelve factors comprise the following ones:

- Wrist-finger-speed: Tasks with high factor loadings on this factor require the participant to perform quick and rapid wrist flexing and finger movements. A typical task is to tap quickly with a pencil in a large circle, where no careful positioning of the pencil is required.
- Finger dexterity: Tasks loading high on finger dexterity requires the participants to coordinate finger movements when executing fine manipulations. A typical task is to grasp, release, or manipulate small objects (e.g., pins).
- Rate of arm movement: The relevant variable is the speed with which gross and rapid arm movements can be performed.
- Aiming: Aiming is defined as the ability to perform a series of accurately directed movements requiring eye-hand coordination as quickly as possible. Compared to the wrist-finger-speed, the tasks with high factor loadings on aiming require eye-hand coordination. For example, if the circle, in which the tapping must be performed, is getting smaller, the task will have higher factor loadings on aiming.
- Arm-hand-steadiness: Arm-hand-steadiness is the ability to execute precise and accurate arm-hand movements without strength and speed.
- Reaction time: This factor represents the speed with which the participant can react to a stimulus, whenever it appears.

- Manual dexterity: Tasks with high factor loadings on manual dexterity require the participant to make skilled arm-hand movements. Compared to finger dexterity, these tasks require gross movements also involving the arm.
- Psychomotor speed: This factor was not clearly defined by Fleishman and was only described as the speed required to mark answers.
- Psychomotor coordination: It demonstrates the coordination of gross movements of the body; however, a clear definition could not be given based on the data from Fleishman.
- Spatial relations: The factor describes the ability to relate different responses to different stimuli with spatial order.
- Postural discrimination: Tasks with high factor loadings on the postural discrimination factor require the participants to make precise bodily adjustments without having any visual cues.
- Error and correct scores on the hand-precision aiming: Fleishman also had problems identifying this last factor. It only loaded high on the error and correct scores of the hand-precision aiming tasks.

The procedure of Fleishman (1954) to provide a classification of individual differences regarding psychomotor abilities was data-driven: He first hypothesized these twelve factors based on earlier study results (see e.g., Fleishman, 1953a; Fleishman & Hempel, 1954a, 1954b; Hempel & Fleishman, 1955). In order to measure these hypothesized factors, Fleishman (1954) constructed at least three tests to measure each factor and included the Air Force psychomotor test in a second step. These tests were administered to 400 participants. From the resulting correlation matrix between the various psychomotor tasks twelve factors were extracted by Thurstone's centroid method (1947) and rotated orthogonally based on Zimmerman's graphical method (1946). A simple structure resulted.

The specific psychomotor ability or the set of psychomotor abilities required to perform the operations in a given situation determines the performance level which can be reached when the situation is familiar, but it also determines the adaptation process. The individual pattern of psychomotor abilities across the twelve psychomotor factors introduced is expected to indirectly change the plan realized to achieve the goal. It is assumed that a human being chooses the ideal way of operations to succeed considering his/her capabilities.

8. Theoretical Overview

In accordance with Brunswik (1937) it is assumed that human beings are highly sophisticated in achieving their goals in life. The process of how human beings achieve this high level of sophistication was analyzed theoretically in terms of information acquisition, human behavior and determining variables.

Theories classifying different modes of human behavior, of information acquisition and underlying cognitive processes have been introduced. As a variable linking these classes of human behavior and information acquisition, the adaptation to a new situation has been discussed and a continuum proposed between these various classes of behavior and information acquisition: When confronted with a totally new situation, only proximal variables are perceived, exploratory and knowledge-based behavior takes place. In contrast, when fully adapted, direct perception of a situation and direct activities occur. As cognitive processes underlying these adaptation processes of human behavior and information acquisition, the formation of an internal representation of the situation, mental simulation of ways of how to satisfy the human motive, the formation of actions and specifying the relevant information in the environment and, last, the direct perception of a situation and the direct reaction have been proposed. Hence, the information processing requirements decrease with continuing adaptation to a situation. Based e.g., on research results in the field of skill acquisition, variables relating to the actor/observer and to the situation have been defined, which might make the adaptation process unnecessary, assist it, hinder it or make it impossible. Such variables mainly refer to the intelligence of the actor/observer, the psychomotor abilities required, the complexity of the situation and its consistency.

Whether the proposed cognitive processes underlying the assumed continuum of adaptation to a new situation regarding information acquisition and human behavior hold will be tested in the following, as is its proposed interaction with the variables reflecting individual differences.

EMPIRICAL EVIDENCE

9. Research Questions and Hypotheses

An adaptation process to a new situation was described in the previous section based on an information acquisition – behavior circle considering characteristics of the actor and the situation. A study was conducted in order to test major theoretical assumptions underlying this adaptation process. The research questions and hypotheses are described in the following.

9.1. Research Questions and Hypotheses: Information Perception and its Interaction With Individual Differences

Information acquisition as described in Section 5.7 can be – based on the underlying cognitive processes – artificially divided in three phases:

In a first phase, an internal representation of the situation is built, based on which action planning takes place. To build this cognitive model, proximal variables are perceived and linked based on potential plans to perform the actions required to achieve the activity. This process is expected to be highly dependent on the cognitive abilities, i.e., the intelligence of the actor.

Hence, two major assumptions are made (for a summary, see Table 5):

First, it is expected that for successfully building the cognitive representation of the situation, the actor needs to perform more gazes than are actually required for executing the operations. Hence, with increasing exposure to the new environment, the number of gazes should decrease. The individual differences determine the different decreases between actors, as more intelligent actors will need a smaller number of gazes to build this representation as do less intelligent actors. It is further expected that this representation is dependent on the task which the actor aims at achieving in this new environment implying that more task-related gazes are executed than necessary when the situation is familiar. Presumably irrelevant objects are not looked at. Thus, the number of task-related gazes in relation to the total number of gazes executed decreases with the number of practice trial. It is expected that this decrease depends on the intelligence of the participants. Parallel to the reasoning given above, the participants with greater intelligence measures will require fewer gazes in order to build the cognitive representation.

Second, it is expected that the representation is a tool used in order to plan future actions and to check whether they are appropriate for achieving the goal in question or not. Hence, the number of formulated plans decreases with the familiarity of the situation; this decrease is expected to interact with the intellectual abilities of the actors: While more intelligent actors will need to work out a smaller number of plans, the number of plans is greater for less intelligent participants.

The individual differences in relevant abilities do not only significantly determine the individual differences in situation adaptation, but also in the duration of the situation adaptation: It is expected that the differences in the average duration of a gaze, in the average duration of a task-related gaze in relation to the average duration of all gazes, and in the average duration of a formulated plan can be determined based on differences regarding relevant cognitive abilities, as the information processing is expected to be shorter for a person with greater intelligence in comparison with a person with smaller values.

Despite these interaction effects, it is also expected that the average duration of all gazes, the average duration of task-related gazes in relation to the average duration of all gazes and the average duration of a formulated plan decrease with the familiarity of the situation, as the information acquisition is, generally speaking, enhanced when the piece of information is familiar.

Table 5

Hypotheses and According Identifiers Testing the Major Assumptions Underlying the First Phase of the Adaptation of the Information Acquisition and its Interaction With the Ability Measures

Identifier	Hypotheses
H^I_1	The total number of gazes decreases linearly with the number of practice tasks performed. This decrease interacts with intelligence.
H^I_2	The average duration of a gaze decreases linearly with the number of practice tasks performed. An interaction with intelligence is expected.

H^I_3	The total number of task-related gazes in relation to the total number of gazes executed decreases linearly with the number of tasks performed. This decrease interacts with intelligence.
H^I_4	The average duration of a task-related gaze in relation to the average duration of a gaze decreases linearly with the number of tasks performed. An interaction with intelligence is expected.
H^I_5	The total number of plans formulated decreases linearly with the number of tasks performed. This decrease interacts with intelligence.
H^I_6	The average duration of a plan decreases linearly with the number of tasks performed. An interaction with intelligence is expected.

After the initial phase of the adaptation process and the internal representation has been built, informal cues represent anchors to actions allowing achieving the goal in question. It is expected that the gazes on the objects used as anchors are longer than the average gaze duration (see Table 6), as more information needs to be transported.

Table 6

Hypotheses and According Identifiers Testing the Major Assumptions Underlying the Second Phase of the Adaptation of the Information Acquisition and its Interaction With the Ability Measures

Identifier	Hypothesis
H^I_7	The average gaze duration on an anchor minus the average gaze duration changes with the number of tasks performed and interacts with the intelligence of the actors. The relationship of the change is expected to be shaped like an inverted “u”.

In the third and last phase of the adaptation process towards a new environment, the situation itself is perceived, which directly indicates the operation allowing reaching the goal in question. As long as the situation does not change and is well known, the gaze behavior and the operations performed run more and more parallel. Anticipatory behavior is no longer required, so that the number of operation-independent gazes decreases and the differences between the start dates of the gazes and the according operations approaches zero with the familiarity of the situation (see Table 7). Another effect of the alignment of gaze behavior and operations is that the gaze duration on an object can be predicted by this object's relevance for goal attainment. Distractions due to e.g., building the cognitive representation of the environment, do no longer occur. This is why it is further expected that the average duration of the operation-independent gazes in relation to the average duration of all gazes decreases with the number of practice trials. The still occurring operation-independent gazes only serve the purpose to detect possible changes in the situation, which might make fine-tuning of the operations necessary.

This general change of the information acquisition is also expected to be influenced by individual differences: As it can be expected that checking the environment for possible changes requiring an adjustment in the execution of the operations takes place, while the current operation does no longer require the attention of the actor, individual differences regarding intelligence factors do not influence that process but psychomotor abilities do. This is the case as psychomotor abilities determine e.g., how quick operations can be executed. The same pattern is the case regarding the average duration of the operation-independent gazes in relation to the average duration of all gazes: The duration of the gaze is no longer determined by the requirement to process new information. Only if new information is available, the gaze duration is influenced by the level of intelligence. However, intelligence is expected to determine the change of the average difference between the start dates of the gazes and the according operations. The anticipatory character of the gaze behavior is expected to decrease with the familiarity of the situation. This decrease is expected to be determined by the level of intelligence, as the planning component is reduced with the number of tasks performed.

Table 7

Hypotheses and According Identifiers Testing the Major Assumptions Underlying the Third Phase of the Adaptation of Information Acquisition and its Interaction With the Ability Measures

Identifier	Hypotheses
H^I_8	The total number of operation-independent gazes in relation to the total number of gazes decreases linearly with the number of practice trials performed. The change is expected to be influenced by the psychomotor abilities of the participants.
H^I_9	The average duration of operation-independent gazes in relation to the total number of gazes decreases linearly with the number of practice trials performed. An interaction of the decrease is expected to take place with the participants' psychomotor abilities.
H^I_{10}	The object relevance is a significant predictor for the gaze duration when the situation is familiar.
H^I_{11}	The average difference between the start dates of gazes and operations decreases linearly with the situation's familiarity. The intelligence level of the participants interacts with the expected decrease.

9.2. Research Questions and Hypotheses: Human Behavior and its Interaction With Individual Differences

An adaptation process to a new environment has also been proposed regarding human behavior (see Section 6.4). Parallel with the adaptation process regarding information acquisition, the phenomenology of human behavior can artificially be classified in three phases based on the proposed underlying psychological processes. This classification does, however, not run in parallel with the three phases described regarding information acquisition.

In the first phase, a cognitive representation of the new situation and how the task can be accomplished is worked out, as described in the previous section. For this purpose, not only gaze behavior is executed, but also creative actions or exploratory behavior. Both complement the visual information and yield significant feedback about the environment's features. The exploratory behavior manifests itself in the number of task-irrelevant operations, defined as the number of operations which are not related to achieving the goal in question. If the exploratory behavior supports the formation of an internal representation, the number of exploratory behavior should decrease in relation to the total number of operations executed (see Table 8). Due to the informational value of the task-irrelevant operations, it is also expected that not only their number but also their duration decreases with increasing familiarity of the situation. Due to the high cognitive work load when building the internal representation, it is expected that the intelligence factors and especially the processing capacity determine the course of the described dependent variables.

Table 8

Hypotheses and According Identifiers Testing the Major Assumptions Underlying the First Phase of the Adaptation of Human Behavior and its Interaction With the Ability Measures

Identifier	Hypothesis
H^B_1	The total number of task-irrelevant operations in relation to the total number of operations decreases linearly with the number of tasks performed. The decrease is influenced by the intelligence factors.
H^B_2	The average duration of the task-irrelevant operations in relation to the average duration of the total number of operations performed decreases linearly with the number of practice trials performed in a linear way. An interaction effect with the intelligence factors is expected.

In a second phase it is expected that feedback from the executed operations is used to complement the internal representation and allow working out an optimal realization of the required operations. For this purpose, changes at two levels of abstraction occur: First, the way operations are executed changes, which can be measured based on the speed with which they are carried out. This is why it is expected that the average duration of an operation decreases with the number of practice trials performed (see Table 9). Parallel with the above reasoning, it is expected that the intelligence measures influence the change of the average duration of an operation: More intelligent participants are expected to determine more efficient ways quicker than do less intelligent participants. Second, different combinations of operations and their impact on successful performance are tested by the participants. The number of strategic shifts is, thus, expected to change. However, this testing will only be initiated when the internal representation is more elaborated, so that an initial increase should be at hand, which decreases when the situation is more familiar. Hence, an inverted “u”-shaped course of this variable is expected, in contrast to the anticipated linear declines of the other dependent variables. Again, it is expected that the number of strategic changes is influenced by the level of the participants’ intelligence, as more able participants will find ways to achieve better results more quickly than do less able participants. Besides, the psychomotor abilities are expected to have an effect on the number of strategic changes as well: For participants with a greater degree of relevant psychomotor abilities, it is of less importance to define the, for them ideal combination of operation. For example, the strategy requiring more power compared to another strategy will only be chosen by someone having a sufficiently high power level.

Table 9

Hypotheses and According Identifiers Testing the Major Assumptions Underlying the Second Phase of the Adaptation of Human Behavior and its Interaction With the Ability Measures

Identifier	Hypothesis
H^B_3	The average duration of an operation is expected to decrease linearly with the number of practice trials performed. It is further expected that the decrease interacts with the intelligence of the participants.
H^B_4	The number of strategic shifts is expected to decrease with the familiarity of the tasks. An interaction effect of this decrease with the psychomotor abilities and the intelligence factors is expected.

After the cognitive representation has been developed on the basis of the sensory information and feedback on the executed behavior and promising actions have been worked out based on mental simulation, the operations, which were initially actions or even activities, are grouped, which is – as it is a cognitive process – influenced mainly by the intelligence factors. Hence, the number of actions performed decreases with the familiarity of the situation (see Table 10).

Table 10

Hypothesis and According Identifier Testing the Major Assumption Underlying the Third Phase of the Adaptation of Human Behavior and its Interaction With the Ability Measures

Identifier	Hypothesis
H^B_5	The number of actions performed is expected to decrease with the number of practice trials. The intelligence factors are expected to determine this decrease.

10. A Priori Power Analysis and Sample Size Estimation

It is a crucial step in planning a study to decide on the required sample size so that the derived statistical judgments are accurate and reliable without wasting resources. The latter is the case when the sample size is too high and only minimal gain is achieved by testing many more participants than required. However, if the sample size is too low, the statistical power might not be sufficient to detect a – in the real-world – existing effect.

The optimal sample size *N* depends (1) on the effect size f^2, (2) on the power (1-ß), and (3) on the alpha level (α). The effect size is a measure of the strength of the relationship between the variables of interest. In this context, f^2 is, for example, the difference of the total number of gazes executed to complete the first and the last practice trial. Conventions have been developed to judge on the size of an effect (Cohen, 1988, 1992). As in this context, the *F*-distribution is used, the following conventions are applied:

- small effect: $f^2 = 0.02$
- medium-sized effect: $f^2 = 0.15$
- large effect: $f^2 = 0.35$

The power of a study is the probability of correctly rejecting the null hypothesis. Hence, the power of a study refers to the probability to find what was looked for in the study and should, as such, be kept high. Conventions specify that the power of a study should be at least 1 – ß = .80.

Last, the alpha level, also referred to as Type-I-Error, is the probability of rejecting the null hypothesis although it is the correct state of the world. The alpha level should not exceed $\alpha = .05$.

In order to calculate the optimal sample size, a two-step procedure has been chosen (Cohen, 1988): In a first step, the degrees of freedom of the error term (df_e) were calculated. For this purpose, the noncentrality parameter λ of the noncentral *F* function was determined with the tables given in Cohen (1988, page 448). The alpha level has been set to $\alpha = .05$, the power to $1 - ß = .80$, and the degrees of freedom of the source to $df_s = 3$, i.e., the number of practice trials minus one (for a decision on the number of practice trials performed, see Section 11.1). The calculations have been repeated with a small, medium-sized and large effect according to Cohen (1988). As λ is also a parameter of df_e, an initial value df_e' was assumed and later checked for correctness. The initial value for df_e' was set to $df_e' = 120$, the second analysis was performed with $df_e' = 60$ and the last one with $df_e' = \infty$. The best estimation for df_e' is the one for which the deviation between df_e and df_e' is minimal. The equation for calculating df_e on the basis of f^2, λ and df_s is given in Equation 1.

$$df_e = \lambda / f^2 - df_s - 1 \quad (1)$$

As df_e also depends on the sample size, *N* can be calculated in a second step when df_e has been determined and the number of independent variables x is known. The number of independent variables is highest for the hypotheses testing the two-way interaction between the repeated measurements of the dependent variables and the ability measures. It is expected that two control variables will result as aggregates out of all measured control variables (see Section 15.2.3) and one analysis will be performed for each variable of individual differences. Hence, the maximum number of variables included as independent or control variables is x = 3.
Equation 2 explains how the sample size can be calculated.

$$N = df_e / df_s + x - 1 \quad (2)$$

The results for both steps of the conducted a priori power analysis are given in Table 11.

Table 11

Results of the a Priori Power Analysis

Assumed effect size f^2	df_e	N
	First analysis: df_e' = 120 (λ = 11.1)	
0.02	551.00	186
0.15	70.00	26
0.35	27.71	11
	Second analysis: df_e' = 60 (λ = 11.5)	
0.02	571.00	193
0.15	72.67	27
0.35	28.86	12
	Third analysis: df_e' = ∞ (λ = 10.9)	
0.02	541.00	183
0.15	68.67	25
0.35	27.14	11

The above given results for the second analysis performed are interpreted, as the differences between df_e and df_e' are smaller than the ones for the first and third analysis. The following sample sizes result:

- 12 participants are required to detect a large effect.
- 27 participants are required to detect a medium-sized effect.
- 193 participants are required detect a small effect.

Due to the resources required for testing the participants and for analyzing the data, it was not possible to collect data on 193 participants. Hence, the sampling procedure aimed at ideally testing 27 participants, but not less than 12 participants should take part in this study.

11. Course of the Study

The study took place in two sessions. In the first session, which lasted between one and two hours, the participants conducted a gardening task, during which the eye fixation and movement data was recorded by an eye tracker (see Section 13.3). This session was performed with one participant each. In a first step, the informed consent was thoroughly explained and signed by the participants. Then, the eye tracker was put on by the participants and the calibration procedure was started in order to allow the eye tracking software to put the pupil position in relation to a point in the scene video, i.e., the point the participant is looking at (for further explanations, see Section 13.3.2). The calibration procedure was performed with five dots on a wall. The participant had to fixate these dots in a given order as indicated by the experimenter. The distance between the person and the dots was about 1m, i.e., the distance in which the error of the eye tracking system in determining the gaze position was minimal. When the person has fixated the indicated dot, the eye position was recorded by the eye tracking software. The accurate functioning of the calibration and, hence, the eye tracking was validated by asking the participant to fixate some given landmarks in the room in which the study took place. After the successful calibration procedure, the recording of the scene video with the gaze position was started. Next, the participants were instructed about how to execute the gardening tasks (see Appendix A). This task was chosen as wheelchair users usually have no experience with gardening tasks in general. Due to the necessity of working e.g., in mud, wheelchair users are not applicable for learning the gardening profession in their vocational education, from which the participants were recruited (see Section 14). Hence, it was an optimal task for analyzing human adaptation processes. The instructions explained the general activity, the participants had to perform. More specifically, the participants had to lead a little market garden and prepare the products customers wanted to buy (see Appendix B). The products and related activities to be taken can be sorted in two categories: sowing seeds and setting in seedlings. In order to sow the requested seeds (either sunflower or ramson seeds) the following actions were required:

- The pots had to be placed in the seed box.

- Soil had to be loosened and filled into the pots.
- A hole had to be made into the soil in the pot.
- One seed had to be filled in each hole.
- If the seeds were light germinators (indicated on the customer request), the holes had to be covered by wettish newspaper pieces.
- If the seeds were dark germinators (also indicated on the customer requirement), the holes had to be covered with a little bit of soil.
- The pots with the seeds had to be watered; whereas the water had to have a in the instruction given temperature and acid value.

In order to set in the seedlings, the following actions had to be performed by the participants:

- An appropriate pot had to be filled half with loosened soil.
- The seedlings (either flowering or foliage plants) had to be put into the pot.
- The correct fertilizer had to be chosen (as indicated in the instructions).
- The pot had to be filled with alternating layers of appropriate fertilizer and soil.
- The plant had to be watered with water with a temperature of 25° degrees and an acid value between five and six, as indicated in the instructions.

Four customer requests had to be executed (see Appendix B): The first required the participants to sow sunflower seeds, the second to set in flowering seedlings, the third to set in foliage plants, and the last customer requested sowed ramson seeds. It was decided to only work with these four customer requests due to the amount of time required and because participants with some deficiencies (see Section 14) were expected to have problems maintaining attention for such a prolonged time frame.

All material required was distributed in the environment of the participant (see Figure 16):

On a long bank (see Figure 16 and Figure 17), standing in the back of the room, there was a screwdriver, pencils, erasers, a pencil sharpener, acidity test strips, a thermometer, nitrogenous fertilizer, phosphoric fertilizer, sunflower seeds, ramson seeds, salt, vinegar, newspapers, big pots, and towels. This bank was about 3.95m long and 0.28m wide.

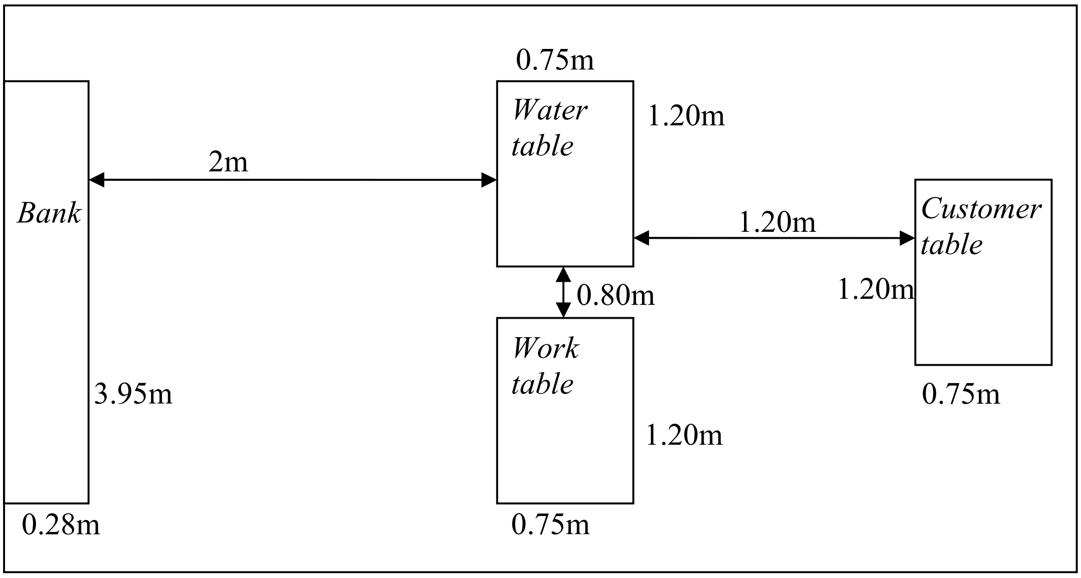


Figure 16. Floor plan of the room in which the study took place.

Figure 17. Bank on which most of the material required for the tasks was distributed.

The other tables, i.e., the water table, the work table and the customer table, were 0.75m wide and 1.20m long. At the customer table, the participants had to pick up the card with the next customer request, at the water table, the participants had to collect small white cups containing water, and at the work table (see Figure 18), the seed box with further pots, a box with soil and a scoop, as well as all plants required for executing the customer requirements were located. At the work table, the participants performed the required operations and actions.

Figure 18. Work table with the soil box, the seed box, the pots, the scoop, and the plants (the customer table is visible in the background).

After having executed all customer requests, the eye tracker was switched off and the participants were allowed to take it off. Last, they had to perform some tasks testing their psychomotor abilities (see Figure 19, Section 13.2, and for instructions see Appendix C).

The second session also lasted about 1.5 to 2 hours, but was performed in group sessions with a maximum of ten participants. As an icebreaker, the participants filled in the biographical questionnaire (see Appendix D), before the selected items of the intelligence test was performed (see Section 13.1). As a reward for participation, the wheelchair users received a voucher for the local cinema and were released from their vocational education while participating in the study (for a description of the sampling procedure, see Section 14).

11.1. Number of Practice Trials Performed

The number of practice trials the participants had to perform varied based on the activity: As described in the previous section, the activities sowing in seeds and setting in seedlings can be distinguished. The first activity was performed ten times, the second one seven times. These numbers emerge as the different customer requests require the participants to complete different numbers of sowing in seeds or setting in seedlings: Sowing seedlings was requested by two customers, both of which asked for five pots with sowed seeds. Setting in seedlings was also requested by two customers, the first asked for three pots, the second one for four.

The number of activities to be performed by the participants was selected based on two criteria: On the one hand the participants should be able to adapt to the situation in the given time frame; on the other hand, the participants should not loose attention or motivation in trying to achieve good results. The latter is the reason why the duration of the practice session was limited to a maximum of two hours. Within this time frame, most of the participants were able to complete the described activities. A simpler, less complex task was not considered, as the task should display realistic everyday activities.

12. Description of the Variables

In the study, three types of variables are to be distinguished: dependent variables, independent variables, and control variables. Each is thoroughly described in the following starting with the independent variables:

- The intelligence factors processing capacity (K), processing speed (B), memory (M), figural abilities (F), numerical abilities (N), and verbal abilities (V) were measured with the “Berlin Intelligence Structure Test – Version 4” (see Section 13.1).
- The psychomotor abilities were measured with the “Motorische Leistungsserie” (see Section 13.2). More specifically, the factors steadiness (ST), precision of arm-hand movements (PR), velocity of arm-hand movements (VE), and the speed of wrist-finger movements (TP) were assessed.
- To define the relevance of an object, for each operation (for a description of all operations, see Appendix E) a target object was defined (for a mapping of operations and objects, see Appendix F) based on the analyses of the eye

tracking videos (see Section 13.3). As a target object, the Pot 1 was chosen, as it played a significant role for achieving all four practice trials. The number of operations this target object was used for was divided by the total number of operations. The resulting value is the relevance (OR) for the target object for each task (OR-T1, OR-T2, OR-T3, OR-T4).

The dependent variables were all calculated on the basis of the analyses of the eye tracking videos (for a description see Section 13.3) and are listed in the following:

- The total number of gazes (NG) within each trial (NG-T1, NG-T2, NG-T3, NG-T4) referred to the number of time periods any object was looked at.
- The average duration of the gazes (DG) within each trial (DG-T1, DG-T2, DG-T3, DG-T4) was measured in 1/60 seconds and calculated by dividing the sum of the duration of all gazes by the total number of gazes performed.
- The number of task-related gazes in relation to the total number of gazes (NRG) within each trial (NRG-T1, NRG-T2, NRG-T3, NRG-T4) was calculated by subtracting the number of gazes on task-irrelevant objects (for a list of task-irrelevant objects see Appendix G) from the total number of gazes for all practice trials and by dividing the result by the total number of gazes for each trial.
- The average duration of task-related gazes in relation to the average duration of all gazes (DRG) within each trial (DRG-T1, DRG-T2, DRG-T3, DRG-T4) was calculated as follows: The duration of all task-related gazes measured in 1/60 seconds was divided by the number of task-related gazes. The resulting value was divided by the result of the division of the duration of all gazes measured in 1/60 seconds and the total number of all gazes.
- The number of formulated plans (NPL) for each practice trial (NPL-T1, NPL-T2, NPL-T3, NPL-T4) was counted based on the order of the gazes. In order to be considered a plan, the gazes should be related to objects with which a future operation can be associated.
- The average duration of a plan (DPL) for each practice trial (DPL-T1, DPL-T2, DPL-T3, DPL-T4) was calculated by adding the durations (measured in

1/60 seconds) of all gazes within each plan as defined before and by dividing it by the number of all plans performed.

- The average difference between the average duration of a gaze on an anchor and the average duration of a gaze on an object (DAG) for each practice trial (DAG-T1, DAG-T2, DAG-T3, DAG-T4) was calculated as follows: First, an anchor was defined as the first object looked at within an action (for the definition of an action, see below) and the durations of the gazes on anchors (measured in 1/60 seconds) were summed and divided by the number of actions performed within each trial. Second, the average duration of a gaze on any object (measured in 1/60 seconds) was subtracted from the average duration of a gaze on an anchor.
- The number of operation-independent gazes in relation to the total number of gazes (NIG) for each practice trial (NIG-T1, NIG-T2, NIG-T3, NIG-T4) was calculated by comparing the operations and the gazes. A gaze was defined as operation-independent if the object of interest for the operation was not looked at in the course of the operation. Appendix F gives the mapping between the operations and operation-relevant objects, which was used as a basis for the above mentioned comparison.
- The average duration of the operation-independent gazes in relation to the average duration of a gaze (DIG) for each practice task (DIG-T1, DIG-T2, DIG-T3, DIG-T4) was determined by summing the durations of all already defined operation-independent gazes. The resulting total duration was divided by the total number of operation-independent gazes. This average duration of an operation-independent gaze (in 1/60 seconds) was divided by the average duration of a gaze, which was also measured in 1/60 seconds (i.e., the division of the total duration of all gazes and the number of all gazes for each practice trial).
- The duration of a gaze on an object (DGO) for each practice trial (DGO-T1, DGO-T2, DGO-T3, DGO-T4) was calculated by subtracting the start and end times of the gaze on that object. The resulting durations of all gazes on an

object (measured in 1/60 seconds) were summed and divided by the total number of gazes on that object. As an example object, Pot 1 was chosen.

- To calculate the average difference of the start dates of the gazes and operations (SDG) for each practice trial (SDG-T1, SDG-T2, SDG-T3 and SDG-T4), in a first step a target object for a gaze was defined for each operation (see Appendix F). In a second step, the difference between the start dates of the gazes and the according operation was calculated (in 1/60 seconds) and divided by the total number of matching gazes and operations. Gaze-independent operations and operation-independent gazes were excluded for calculating this variable.
- The total number of task-irrelevant operations (see Appendix H) in relation to the total number of operations (NIO) for each practice task (NIO-T1, NIO-T2, NIO-T3, NIO-T4) were calculated in two steps: First, a list of operations has been defined (see Appendix E) which did not contribute to reaching the goal of the task. Second, the number of these task-irrelevant operations were counted and divided by the total number of operations executed.
- The average duration of the task-irrelevant operations in relation to the average duration of all operations (DIO) was calculated for each practice trial (DIO-T1, DIO-T2, DIO-T3, DIO-T4) by summing all durations of all task-irrelevant operations (in 1/60 seconds) and by dividing the result by the average duration of an operation (in 1/60 seconds).
- The average duration the participants required for one operation (DO) within the practice trials (DO-T1, DO-T2, DO-T3, DO-T4) was calculated based on the time stamp in the videos of the eye tracking data (see Section 13.3). More specifically, the end dates and the start dates for each operation were subtracted and all results added to reach total duration of all operations for each participant and for each practice trial (in 1/60 seconds). The total duration of all operations was divided by the number of operations which were executed. A list of operations is given in Appendix E.

- The number of strategic changes (NST) for each practice trial (NST-T1, NST-T2, NST-T3, NST-T4) was calculated by counting the number of times, each participant changed the way he/she executed operations and/or actions.
- The number of actions (NA) for each practice trial (NA-T1, NA-T2, NA-T3, NA-T4) was calculated by counting the number of grouped operations without periods of uncertainty and/or rest periods. A period of uncertainty was defined as comprising insecure behavior including e.g., breaks, routing, reading instructions, reading customer requirement, or asking for help. A rest period was defined as a break. Hence, by definition, after each action, either a rest period or a period of uncertainty results.

The control variables were measured based on the biographical questionnaire (see Appendix D) and cover experience and interest with agriculture, as well as personal indicators such as the type of disability and related handicap, or stage of education. More specifically, the variables comprise the following ones:

- Interest in agriculture: Participants with an interest in agriculture might be familiar with the order in which operations/actions are required to achieve the gardening tasks and, thus, bias the results.
- Practical experience with agriculture: Participants with practical experience with agriculture might achieve better results as well, for example, due to experience with the operations required to successfully achieve the gardening task. It was tried to keep the experience with agriculture as low as possible, by choosing this task (see also Section 11).
- Age: Age has been included in the study as a control variable as age can play an important role in the type and degree of the remanent abilities.
- Gender: Gender plays an especially high role, when figural/spatial abilities are involved (see e.g., Halpern, 1992).
- Handedness: The work table (see Figure 18) was organized to best support right-handed participants. The soil box on the left of the work table might have made the executions of the operations more difficult for the left-handed participants.

- Type of disability: The disability might hinder the actions and operations performed. Some participants can, for example, only move their arms with the support of the other hand, so that especially the time to perform an operation is biased depending on the type of disability.
- Degree of disability according to the severely handicapped pass: In the severely handicapped pass, the degree of disability or the severity of the disability is indicated in terms of degree of help the person requires. Hence, this might also influence the help the participant will request while executing the gardening task.
- Type of wheelchair (manual or electrically powered): The type of the wheelchair the participants used in the study was recorded as well as a control variable. The participants had to drive around while completing the operations. The way they choose (e.g., between the tables or around them) might depend on the type of wheelchair and influence the timing of the operations.
- Last degree earned from a general-education school: As for entering the different kinds of vocational education different levels of education are applicable, this variable was also included in the study.
- Current stage of educational training (i.e., defining an appropriate profession, course for career advancement, vocational education): The participants go through various stages while learning a profession. The stage is of importance, as the experience with work might influence the diligence the participants take in order to perform the gardening tasks.
- Number of years of passed in vocational education: The total number of years in vocational education can be four years. As work experience might have an effect on the outcome of the study (see before), data on this variable were gathered.
- Type of vocational education (orthopaedic shoemaker/mechanic, home economics and nutrition, design of media and print, electrical engineering, metal engineering, economy and administration): The type of vocational education might influence the study's results as e.g., orthopaedic

shoemaker/mechanic might be better in performing manual tasks as are participants in the vocational education of administration.

Due to the small sample size, not all control variables have been included in the analyses. Instead, data aggregation has been performed, which is thoroughly described in Section 15.2.3.

13. Apparatus and Material Used

13.1. Material Used for Collecting Data on Perceptual Processing, Processing Speed and Content Abilities

Processing capacity (K), processing speed (B), memory (M), figural abilities (F), numerical abilities (N), and verbal abilities (V) were measured with the Berlin Intelligence Structure Test (BIS-4), which was developed by Jäger, Süß, and Beauducel (1997) and is thoroughly described in the following.

13.1.1. Items

The items of the BIS-4 are a selection from the item pool derived for developing the Berlin Intelligence Structure model (BIS). The original pool comprises all items used before in the history of research for analyzing intelligence and creativity, except those covering practical and social intelligence and those requiring self-assessments. A representative set of 191 items was applied in a study conducted by Jäger (1982, 1984), which results were used for developing the BIS. Out of the 191 items, 45 items were selected in order to yield an intelligence test, which satisfies economical needs and maximizes the similarity between the variance of the factor loadings and the variance of the scale values. In the following, the items measuring processing capacity and memory were revised to comprise only items, which are similar in respect to their type and to their index of difficulty. The items testing B were simplified so that they can be solved easily with unlimited time. The method of analysis for the creativity items was successively improved as well.

The BIS-4 comprises 45 test items, which can be sorted into the BIS model (see Table 12). This distribution is, however, not equal: Jäger, Süß, and Beauducel (1997) have strengthened the items measuring processing capacity and creativity, (1) because processing capacity seems to have a greater impact on external criteria compared to the other factors of intelligence (see e.g., Süß, 1999 and also Section 13.1.5) and (2) because the creativity items demonstrate a reduced objectivity and reliability level (see also Section 13.1.5.). Besides, creativity is not a construct which has thoroughly been investigated, so that its structure and diversity might require more items compared e.g., to processing speed.

Not all items of the test have been used in this study because of time constraints. First, the participants could only leave their vocational education for about 90 minutes; whereas the complete test would haven taken them a minimum of 2.5 hours (Jäger, Süß & Beauducel, 1997). This is especially critical as most of the participants had problems with writing and even with marking a solution in the answer sheets, so that the, in the handbook times allocated for the various items were not considered sufficient for editing the items for the disabled participants. Hence, these times were prolonged (see also Section 13.1.2), which, of course, extended the complete test. Second, the participants were expected to have problems with focusing attention on the test for such a long time period, as neither their school hours nor their working hours required them to pay attention for more than 90 minutes.

Items were excluded measuring intelligence factors which were not expected to significantly account for the dependent variables' variances. Creativity is such an intelligence factor, as creativity is only expected to be relevant for situations, in which neither productions nor help/instructions are available in defining a solution. Regarding the content abilities, it is expected that verbal abilities influence the adaptation to the given situation as the instructions are presented verbally, figural abilities might also have an influence due to the type of actions and operations required and numerical abilities might have the least impact. Dealing with numbers only matters regarding the numbers of pots, the customer request, the ideal water temperature, and the acidity of the water (see also Section 11). Hence, the creativity items were excluded as were one item measuring figural abilities, two items testing verbal abilities and four items assessing the numerical abilities. Altogether, 26 items have been chosen and are also marked in Table 12.

Table 12

Scales and Items of the BIS-4 and the Ones Used in This Study (Adapted From Jäger, Süß, & Beauducel, 1997)

G[a]	F	V	N
B	*Erasing letters*	*Part-Whole*	*X-Greater*
	Old English	*Classifying words*	Divisible by 7
	Number-symbol test	*Incomplete words*	*Calculating characters*
M	*Memory of orientation*	*Meaningful text*	*Pairs of numbers*
	Company's symbols	*Remembering words*	*Two-digit numbers*
	Remembering routes	*Language of fantasy*	Recognizing numbers
C[b]	Layout	Attributes-abilities	Divergent calculating
	Continuing figures	Masselon	Phone-numbers
	Designing objects	Insight-test	Number-equations
	Combining figures	Possibilities of application	Number-puzzle
K	*Analogies*	*Word-analogies*	Array of numbers
	Charkow	*Fact-opinion*	Estimating
	Bongard	*Comparing conclusions*	*Reading tables*
	Selecting figures	Vocabulary	*Arithmetic thinking*
	Winding	Conclusions	*Array of letters*

Note. Items whose names were printed in italics were used in this study.
[a] G = general intelligence. [b] C = creativity.

13.1.2. Test Administration

The test administration is strictly standardized as thoroughly described in the BIS-4's test manual (Jäger, Süß, & Beauducel, 1997). This procedure was changed in two aspects: First, the order of presentation was changed, as not all items were administered (see Section 13.1.1.). In order to maintain attention during the complete testing period, the items were sorted to maximize variety and to minimize frustration due to failure with one category of items. The items were sorted in three blocks, after each a break of ten minutes was inserted in order to reduce fatigue. Second, the time, the participants had available for each item, was prolonged, as the participants had troubles with writing and even marking an answer because of their disability. The designated and actual times for each item are given in Table 13, as is the order of presentation.

Table 13

Designated and Actual Times Allocated for Each Item in the Order of Presentation

Item	Designated time	Actual time
Old English	0:30 min	0:50 min
Memory of orientation[a]	1:30 min	1:30 min
	1:40 min	1:40 min
Analogies	1:45 min	2:00 min
Remembering words[a]	0:40 min	0:40 min
	1:30 min	1:40 min
X-greater	1:00 min	1:15 min
Reading tables	5:00 min	5:00 min
Number-symbol test	1:00 min	1:22 min
Part-whole	0:40 min	0:50 min
Company's symbols[a]	0:50 min	0:50 min
	1:30 min	1:30 min
Array of letters	3:30 min	3:30 min
Erasing letters	0:50 min	0:50 min
Remembering routes[a]	0:30 min	0:40 min
	0:40 min	0:45 min
Bongard	2:10 min	2:15 min
Incomplete words	0:50 min	0:50 min
Pairs of numbers[a]	2:00 min	2:00 min
	2:00 min	2:00 min
Charkow	3:00 min	3:10 min
Classifying words	0:30 min	0:35 min
Winding	2:15 min	2:15 min
Two-digit numbers[a]	1:00 min	1:00 min
	0:50 min	1:00 min

Word-analogies	1:30 min	1:30 min
Arithmetic thinking	3:20 min	3:20 min
Calculating characters	0:50 min	0:50 min
Meaningful text[a]	1:00 min 2:00 min	1:00 min 2:30 min
Comparing conclusions	1:30 min	1:40 min
Language of fantasy[a]	1:00 min 1:50 min	1:00 min 1:15 min
Fact-opinion	1:00 min	1:00 min

Note. [a]The first time is the time allocated for memorization and the second one the time for reproduction.

These changes to the in the test manual prescribed procedure were kept constant overall testing sessions.

13.1.3. Test Analysis

The analysis of the test results followed the instructions given in the test manual (Jäger, Süß, & Beauducel, 1997): The analysis was performed according to items, not according to persons, in order to reduce possible errors. The row scores of each item were calculated for each participant based on the given templates for each item. These row scores were listed in the according protocol as were the standard scores, which were read off the according tables in the test manuals (see pages 85-92 in Jäger, Süß, & Beauducel, 1997). The resulting standard scores were added across the scales of interest: K, B, M, V, N, as well as F. As not all items were used in this study and as the timing of the items was changed (see Section 13.1.2) the standard scores were not directly transferred in the according intelligence score based on the available norm tables. Instead, the missing standard scores were replaced by the means achieved for this scale. The intelligence scores were then read off in the according tables in the test's manual. Caution must be taken when interpreting these intelligence scores, as the scores are based on a different number of items and as the testing procedure has been changed compared to what is prescribed in the handbook.

13.1.4. Norm Tables

The existing norm tables are based on a study with 478 participants from the German speaking part of Switzerland. The participants were 16-19 years old and attended the secondary or grammar school. Separate norm tables for two age groups resulted: 16-17 year olds and 18-19 year olds. To norm tables of the 18-19 year olds were applied in this study, however, as already mentioned in Section 13.1.3, caution must be taken when actually interpreting the intelligence scores of the disabled participants, due to the reduced number of items applied and due to the changed testing procedures (see Sections 13.1.1 and 13.1.2).

13.1.5. Psychometrical Quality Factors

13.1.5.1. Objectivity.

Objectivity refers to the independence of the test results from the test administration and test analysis (Lienert, 1969). Both are judged as given.

First, the independence of the test results from its administration is guaranteed due to the strict standardization, which has been complied with when testing all participants, although the from the handbook prescribed administration has been adapted to meet the special requirements of the study's participants (see Section 13.1.2).

Second, the objectivity of the analysis is also given. All items used in this study were analyzed strictly according to the instructions given in the test manual (Jäger, Süß, & Beauducel, 1997 and see Section 13.1.3). The only test items, which give leeway to the experimenter, are the creativity items, but these have been excluded from this study (see Section 13.1.1.).

13.1.5.2. Reliability.

Reliability refers to the stability of the test results. Reliability coefficients can be calculated based on three methods: First, the same sample is tested twice with the same test. The correlations between the test results indicate the test's reliability. Second, the same sample is tested with another, parallel version of the same test, and again, the correlation between the results gives a measurement of reliability. Third, the test is split and the correlation coefficient between the halves is interpreted as a reliability measurement.

As a parallel version of the BIS-4 does not exist, only the first and third method can be applied to determine the test's reliability. Results for both methods are given in the following:

Süß, Kersting, and Oberauer (1991) tested 137 students twice with the same test with a one-year time difference between the two testing sessions and report retest-reliability coefficients varying between r_{tt} = .65 and r_{tt} = .90 (see Table 14). Similar results have been published by Schmidt, Brocke, Jäger, Doll, and König (1986), and Jäger (1982).

Table 14

Retest-Reliability Coefficients for all Scales of the BIS-4 (Adapted From Süß, Kersting, & Oberauer, 1991)

Scales	B	M	C[a]	K	F	V	N	G[b]
r_{tt}	.86	.74	.65	.90	.78	.80	.87	.88

Note. [a] C = creativity. [b] G = general intelligence.

In all studies applying this method, the lowest reliability coefficients result for the scales creativity and memory, which is also the case for other tests measuring these constructs (see e.g., Sperber, Wörpel, Jäger, & Pfister, 1985). Possible explanations relate to general problems with measuring creativity, task-specific problems or the low stability of creativity over time (see Süß, 1996). Still, the reported retest-reliability coefficients are satisfying and reach an average value of r_{tt} = .81, which refers to 65.6% of explained variance of the total variance. General problems, which might have influenced the results, refer, for example, to the test familiarity or the test nervousness.

Jäger, Süß, and Beauducel (1997) randomly split the test in two halves and calculated the Cronbach's Alpha (see Table 15) as an indicator of the BIS-4's reliability. The Cronbach's Alphas were calculated on the basis of the test items and of the bundles comprising the variables of the facets operations and contents. The latter only derived between three and five independent bundles, so that the results were corrected with the Spearman-Brown-Formula.

Table 15

Internal Consistencies for the Scales of the BIS-4 (Adapted From Jäger, Süß, & Beauducel, 1997)

Scales	B	M	C[a]	K	F	V	N	G[b]
Cronbach's α (Basis: items)	.76	.75	.77	.82	.75	.80	.80	.89
Cronbach's α (Basis: bundles)	.88	.87	.88	.90	.88	.90	.90	.95

Note. [a] C = creativity. [b] G = general intelligence.

However, as Süß (1996) and Jäger, Süß, and Beauducel (1997) report, it is difficult to use these results as appropriate measurements of reliability. The prerequisite for gaining valid internal consistencies is to develop scales in a homogenous way. This does not concord with the model assumptions underlying the BIS-4. The BIS-4 follows the scale construction according to Cattell and Radcliffe (1962) and Cattell and Tsujioka (1964), who propose to accept a limited degree of heterogeneity to reduce the amount of unintended variance. A high amount of unintended variance might decrease the discriminance validity of the scales. Hence, when developing the BIS-4, validity was maximized by controlled heterogeneity, which will balance the not intended variance (see also Humphreys, 1981). Still, keeping in mind that heterogeneity was desired, the Cronbach's Alphas given in Table 15 and measuring homogeneity, are surprisingly high.

13.1.5.3. Validity.

Jäger (1986) suggests distinguishing primarily between three types of validity: construct validity, criterion validity, and content validity. These three validities are discussed in the following regarding the BIS-4.

Jäger (1986) defines the content validity as the representativeness of the test items with a clearly cut population of behaviors which the test intends to measure. Regarding intelligence, however, there is no generally accepted and clearly cut definition of behaviors comprising intelligence, which makes it difficult to develop a content valid intelligence test (see also Sternberg, 1982, 1985). The test items of the BIS-4 were derived from the item pool originally used to develop the BIS model and which comprised all items used so far for measuring intelligence in the history of research on intelligence (see also Section 13.1.1). This is an indicator for content validity, but it is not a guarantee for it, as (1) some tasks have systematically been excluded from this pool, such as the ones measuring practical or social intelligence and as (2) some intelligent behaviors might not have been included in tests developed so far in the history of research on intelligence.

Further crucial is the construct validity, which analyzes whether the test concords with the underlying construct and related theory. Different studies have assessed the construct validity with varying methodologies (e.g., Bucik & Neubauer, 1996; Pfister & Jäger, 1992): Bucik and Neubauer (1996) tested 182 participants (103 females, 79 males; age range: 18-54 years) with the BIS-4 and compared the goodness-of-fit of the BIS with other possible models. These models were the following ones:

- Model 0 referred to the null model.
- Model 1 was the BIS as proposed by Jäger (1982).
- Model 2 comprised only the four operations defined by Jäger.
- Model 3 contained the three variables reflecting the content abilities according to Jäger.
- Model 4 suggested seven factors of intelligence, a unimodal version of Jäger's bimodal theory of intelligence.
- Model 5 was the same one as Model 4 except the difference that the factors were rotated obliquely (Oblimin).
- Model 6 was also the same as Model 4 except that the paths between the manifest and latent variables were set. Only loadings greater than 0.35 were taken into account.
- Model 7 differed from Model 6 by the rotational method. Model 7 made use of an oblique rotation method (Oblimin).

The goodness-of-fit indices Bucik and Neubauer (1996) calculated were the χ^2 and its statistical significance, the adjusted goodness-of-fit index, the root mean square residual (Jöreskog & Sörbom, 1993), the normed fit index and the non-normed fit index (Bentler & Bonett, 1980; Tucker & Lewis, 1973). A summary of the result is presented in Table 16.

Table 16

Summary of the Goodness-of-fit Indices of the Seven Models and the Null Model Testing the Construct Validity of the BIS-4 (Adapted From Bucik & Neubauer, 1996)

Model	χ^2	*df*	*p*	AGFI[a]	RMSR[b]	NFI[c]	NNFI[d]	χ^2/df
Model 0	3962.70	990	.00	0.21	0.26	-	-	4.00
Model 1	894.32	879	.35	0.74	0.09	0.94	1.00	1.02
Model 2	1605.38	939	.00	0.65	0.08	0.59	0.76	1.71
Model 3	2031.41	942	.00	0.56	0.09	0.49	0.61	2.16
Model 4	896.28	879	.34	0.74	0.19	0.94	1.00	1.02
Model 5	902.23	879	.29	0.74	0.14	0.94	1.00	1.03
Model 6	1411.48	913	.00	0.71	0.08	0.64	0.82	1.55
Model 7	1162.42	885	.00	0.76	0.07	0.71	0.90	1.31

Note. [a] = adjusted goodness-of-fit index. [b] = root mean square residual. [c] = normed fit index. [d] = non-normed fit index.

According to the significance of the χ^2 values, Model 2, 3, 5, 6, and 7 can be clearly rejected, which is also supported by the other indices. The two models with the best fit is the one proposed by Jäger (1982) (i.e., Model 1) and Model 4. As the fit indices do not provide a sufficient basis for deciding which is the, from a statistical point of view, better model, the authors reason based on the theoretical background and, thus, favor Model 1. On that basis, the authors conclude that the bimodal structure of intelligence according to Jäger is the model which best fits the data.

As a last step, the criterion validity of the BIS-4 is to be investigated. Various researchers have analyzed the relationship of the BIS-4 results with school grades (see e.g., Kleine & Jäger, 1987; Wittmann & Matt, 1986; Wittmann & Süß, 1996). As another criterion, the results of the university entrance exams in Brazil (Kleine & Jäger, 1989) were used. For this purpose, Kleine and Jäger (1989) applied a Portuguese translation of the BIS-4 and correlated the test results with the results of the university entrance exams of 119 Brazilian students and with the school grades of 164 Brazilian students. The correlations between the BIS-4 scales and the school grades are given in Table 17.

Table 17

Correlations Between the BIS-4 Scales and School Grades (Adapted From Kleine & Jäger, 1989)

	Total[a]	Lang[b]	Nat[c]	Port[d]	Sport[e]	Math[f]	Phy[g]	Chem[h]	Bio[i]	Soc[j]	Geo[k]
G[l]	.48	.38	.48	.34	.15	.45	.42	.26	.36	.48	.23
K	.43	.32	.43	.28	.04	.41	.43	.23	.26	.39	.19
M	.36	.32	.34	.33	.19	.31	.23	.15	.39	.34	.20
B	.35	.26	.35	.25	.10	.34	.31	.18	.25	.38	.16
C[m]	.36	.27	.36	.22	.20	.34	.30	.25	.23	.37	.16
V	.42	.38	.40	.35	.16	.36	.36	.20	.31	.50	.17
N	.37	.28	.37	.21	.10	.35	.35	.19	.27	.32	.24
F	.44	.30	.46	.31	.12	.45	.36	.28	.33	.37	.18

Note. [a] Total = overall average degree. [b] Lang = average degree of all languages. [c] Nat = average degree of mathematics and natural sciences. [d] Port = degree in Portuguese. [e] Sport = degree in sports. [f] Math = degree in mathematics. [g] Phy = degree in physics. [h] Chem = degree in chemistry. [i] Bio = degree in biology. [j] Soc = degree in the social studies. [k] Geo = degree in geography. [l] G = general intelligence. [m] C = creativity.

Generally speaking, the correlations with school grades are lower than the ones usually derived from university entrance exams (see also Kleine & Jäger, 1989). The lower criterion validity can be ascribed to the low reliability of school grades (see e.g., Ingenkamp, 1971).

The differential validity of the BIS-4 is confirmed by the low correlation with the sports grade (e.g., $r_{Sport,K}$ = .04). The verbal abilities have high correlations with all school grades (e.g., $r_{Soc,V}$ = .50); the numerical abilities correlate, as expected, highly with mathematics, physics ($r_{Math,N}$ = .35; $r_{Phy,N}$ = .35) and less with e.g., Portuguese ($r_{Port,N}$ = .21), and, thus, differentiate the average degree of the natural sciences and of the languages. The same pattern is apparent for the figural abilities: They correlate highly with mathematics and physics ($r_{Math,F}$ = .45; $r_{Phy,F}$ = .36), but less with languages ($r_{Lang,F}$ = .30). The processing capacity correlates highly with the overall grade ($r_{Tot,K}$ = .43), however, memory correlates to a greater degree with the languages ($r_{Lang,M}$ = .32) than with chemistry ($r_{Chem,M}$ = .15). Creativity only shows minor correlations, e.g., with the geography ($r_{Geo,Creativity}$ = .16).

The results further demonstrate that the average grades correlate to a greater degree with the BIS-4 scales compared to the single grades of the different subjects. A reason for this might be that the aggregates of the school grades reduce the unwanted error variance and, thus, increase the relationship with the aggregated BIS-4 scales.

These results of Kleine and Jäger (1989) are similar to the ones found by other researchers, such as Wittmann and Matt (1986) or Wittmann and Süß (1996).

13.1.6. Why This Test?

It has been chosen to work with the BIS-4 due to two reasons: First, it measures the scales of interest, which are the content abilities and the operations, of which especially K and B are of importance, as they have demonstrated their predictive validity regarding the skill acquisition (see e.g., Ackerman, 1988; Jipp, Pott, Wagner, Badreddin, & Wittmann, 2004). Skill acquisition is expected to be closely related to the situation adaptation (see Section 4 and 7). Second, the BIS-4 has demonstrated its objectivity, reliability, and validity, in a variety of studies as explained in the previous sections. Potential disadvantages, e.g., related to the objectivity of the creativity items are not applicable here, as creativity is not of interest.

13.2. Material Used to Measure the Psychomotor Abilities

To measure fine psychomotor abilities and especially steadiness (ST), velocity of arm-hand movements (VE), precision of arm-hand movements (PR), and tapping/speed of wrist-finger movements (TP) (Hamster, 1980a), a short form of the "Motorische Leistungsserie" (MLS) was applied (Sturm & Büssing, 1985). The MLS was developed by Schoppe (1974) and is an apparative test for measuring fine psychomotor abilities, which do not require high effort but precision and rapidness (Neuwirth & Benesch, 2004). The underlying factor-analytic structure was oriented towards the empirical results from Fleishman (1954, 1967, 1972b), Fleishman and Ellison (1962), Hempel and Fleishman (1955), as well as, Seashore, Buxton, and

McCollom (1940). In accordance with these results, Schoppe (1974) developed various test items which are organized in the MLS. Various short forms of the resulting test battery exist, the one which was used in this study, is thoroughly described in the following.

13.2.1. Test Platform and Items

The MLS consists of a work disc, which is 300x300x15mm big, and in which various areas of contact, mills, and holes are inserted, with which all items have to be performed (see Figure 19). For this purpose, a red and black stylus are attached to the work disc on the right and left side respectively.

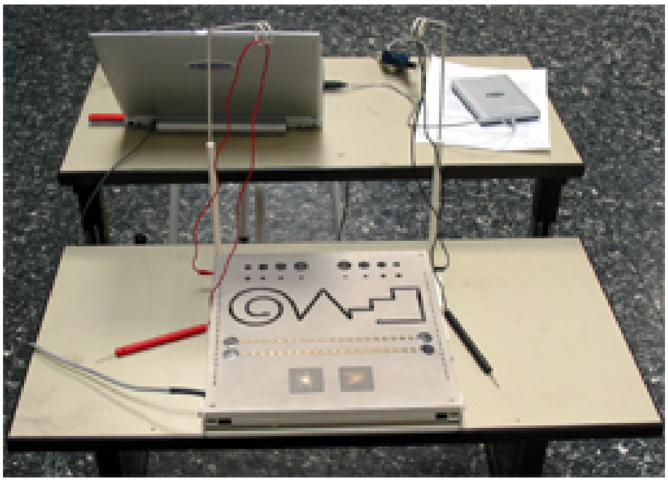


Figure 19. Apparatus of the MLS and setup used for testing the psychomotor abilities.

The participants had to execute all items from the chosen short form of the MLS (Sturm & Büssing, 1985) first, with their right hand (black stylus), then with their left hand (red stylus) (for instructions, see Appendix C):

- The item "steadiness" requires the participants to hold the stylus into a hole with a diameter of 5.8mm without touching the rim or the bottom for a duration of 32 seconds. The test results are an indication for arm-hand steadiness or tremor.
- The item "line-tracing" requires the participant to route the stylus through a countersinked line as quickly and as precisely as possible without touching

the rim or the bottom. This item requires especially fast, confident and complex arm-hand movements.

- The item “aiming” requires the participants to touch 20 metal circles with a diameter of 5mm as quickly as possible and in succession. The diameters have a distance of 4mm. Aiming requires coordination between visual information and hand movements.
- The item “tapping” requires the participants to touch a metal plate on the board with a side length of 40mm with the stylus as often as possible for a duration of 32 seconds. The speed of simple movements at the wrist joint is tested.

13.2.2. Test Administration

The participants performed the MLS items at the end of the first session (see Section 11). For this purpose, the disc was put on a table which height could be adjusted to the sitting position of the participants (see Figure 19). However, the optimal sitting position could not be reached, as the wheelchairs have arm-rests, which should not be the case according to the manual (Neuwirth & Benesch, 2004).

The instructions (see Appendix C) were derived from the ones published in Neuwirth and Benesch (2004) and explained to each participant for both hands separately. First, the items were performed with the right hand, then with the left hand.

The data were saved based on the participant’s fancy name, so that the confidentiality of the data was given.

13.2.3. Test Analysis

The computer-based MLS gave for each participant and item an output file with the individual results for the following variables:

- For the item “steadiness”, the number of mistakes and their duration was automatically counted. Each time, the participants touched the rim or the bottom of the hole, a mistake and its duration were added to the statistics.
- For the item “line-tracing”, it was the number of mistakes (i.e., the number of times, the participant touched the rim or the bottom) and the duration of the

mistakes that were counted and written in the output file. Furthermore, the total duration of tracing the given line was measured.

- For the item “aiming”, the duration of the item was measured by the computer software.
- For the item “tapping”, the number of hits was automatically registered.

Based on the empirical T-values of these variables, the participant’s T-values on the factors ST, PR, VE, and TP were calculated based on Equation 3 (see Neuwirth & Benesch, 2004).

$$T_j = \frac{a_{ij}{}^2 T_i + a_{kj}{}^2 T_k + \ldots + a_{nj}{}^2 T_n}{a_{ij}{}^2 + a_{kj}{}^2 + \ldots + a_{nj}{}^2} \tag{3}$$

T_j = T-value of the psychomotor factor j

$a_{ij}, a_{kj}, \ldots, a_{nj}$ = loading of the variable i, k, …, n on factor j

$T_i, T_k, \ldots, T_n$ = empirical T-value of the variables i, k, … n

The empirical T-values of the variables are automatically written in the output file of the MLS; the factor loadings of the variables on the factors are published in the test’s handbook (Neuwirth & Benesch, 2004). Which variables were used to determine which psychomotor factor is stated in the following:

- ST was calculated based on the empirical T-values of the mistakes and their duration when completing the item “steadiness”.
- PR was calculated based on the empirical T-values of the number of mistakes and their duration when completing the item “line-tracing”.
- VE was calculated based on the duration required for completing the item “aiming” and the item “line-tracing”.
- TP was calculated based on the number of hits when completing the item “tapping”.

13.2.4. Norm Tables

For the short form of the MLS used in this study (Sturm & Büssing, 1985), norms for the population without neurological symptoms (see also Sturm & Büssing, 1985), for the population with Morbus Parkinson (Ringendahl, 1998, 2002) and for clients from the company IEFP in Portugal (see Neuwirth & Benesch, 2004) are at hand.

These norms were not used in this study, first because the test could not be applied as specified, so that the test results cannot be compared with the ones from one of the populations from the norm tables. For example, the participants were all dependent on a wheelchair, but the items should be performed in a chair without arm-rests. Hence, it was not certified whether the results can be transferred to the populations from which norm tables are available.

13.2.5. Psychometrical Quality Factors

13.2.5.1. Objectivity.

Lienert (1969) defines test objectivity as the level of dependency of the test results on the test administrator. Objectivity of the test sessions and of the analysis are to be distinguished.

First, the objectivity of the test session is given. As described in Section 13.2.2 the way the test was administered was kept constant overall participants and the exact procedure was strictly standardized (see Appendix C).
Second, the objectivity of the test analysis is also guaranteed, as it is the case for the majority of computerized tests. The variables of interest of the items administered have been measured automatically and their empirical T-values calculated by the according computer software. The T-values of the psychomotor factors of interest have been calculated as described in Section 13.2.3.

13.2.5.2. Reliability.

Sturm and Büssing (1985) calculated retest-reliability coefficients for all items except steadiness (due to problems with the apparatus, for the results, see Table 18).

200 participants (100 males, 100 females, mean age: 46.91 years) without neurological disorders have been re-tested a day after the first session.

Table 18

Retest-Reliability Coefficients for the Short Form of the MLS Applied in This Study (Adapted From Sturm & Büssing, 1985)

	Right hand		Left hand	
	20-59 year-olds	60-72 year-olds	20-59 year-olds	60-72 year-olds
Line-tracing				
M[a]	.71	.76	.76	.77
MD[b]	.77	.77	.78	.74
TD[c]	.52	.63	.64	.60
Aiming				
TD[c]	.81	.74	.89	.85
Tapping				
HI[d]	.92	.86	.90	.88

Note. [a] M = number of mistakes. [b] MD = duration of the mistakes. [c] TD = total duration. [d] HI = number of hits.

The reliability coefficients vary between r_{tt} = .92 and r_{tt} = .52, and are, as such, smaller as the ones discussed for the BIS-4 (see Section 13.1.6).

Another study also investigating the retest-reliability was conducted by Ringendahl (2002). 114 right-handed participants with idiopathic Parkinson’s disease were tested (77 males, 37 females, mean age: 67.8 years). The second test was conducted 24 hours after the first testing session. The correlations between the test results of the first and second session are introduced in Table 19.

Table 19

Retest-Reliability Coefficients for the, in This Study Applied Short Form of the MLS (Adapted From Ringendahl, 2002)

	Right hand	Left hand
Steadiness		

M[a]	.68	.67
MD[b]	.59	.64
Line-tracing		
M[a]	.71	.80
MD[b]	.62	.60
TD[c]	.64	.80
Aiming		
TD[c]	.48	.61
Tapping		
HI[d]	.73	.73

Note. [a] M = number of mistakes. [b] MD = duration of the mistakes. [c] TD = total duration. [d] HI = number of hits.

The retest-reliability coefficients published by Ringendahl (2002) are smaller than the one introduced by Sturm and Büssing (1985). However, it is to be considered that Ringendahl used a slightly other setting as specified by Sturm and Büssing, especially regarding the item "steadiness". Ringendahl used a hole with a diameter of 8mm instead of 5.8mm applied by Sturm and Büssing. Other differences between the results of the two studies can be traced back first to the age distribution and second to the idiopathic Parkinson's disease the participants were diagnosed with in Ringendahl's study. The impact of age on the level of the psychomotor abilities has been demonstrated by Hicks and Birren (1970) or Welford (1977). While the level of psychomotor abilities is relatively constant in younger years, it drastically decreases in the higher age groups. Further, it is not without problems to transfer data from healthy individuals to participants with neurological disorders.

Hamster (1980b) calculated split-half reliability coefficients for the tapping item with 114 participants with the diagnosis of contusio cerebri, 114 patients with minimal cerebral dysfunction and with 139 patients with a psychiatric disorder (see also Neuwirth & Benesch, 2004). The calculated coefficients reach r_{tt} = .92 for the right hand and r_{tt} = .95 for the left hand.

Summarizing, the reliability coefficients reported by Sturm and Büssing (1985) are on average r_{tt} = .75 for the right and r_{tt} = .78 for the left hand, while the data given by Ringendahl (2002) yield an average retest-reliability coefficient of r_{tt} = .64 for the right and .69 for the left hand. Sturm and Büssing judge the reliability of these items of the MLS as sufficiently high as does Ringendahl. This is supported by the high split-half coefficients derived from Hamster (1980b).

13.2.5.3. Validity.

First, content validity is defined according to Fisseni (1990) as the representativeness of the behaviors evoked by the test compared to the universe of behaviors relevant for the ability of interest. In this context, the relevant ability is fine psychomotor behavior. Meinel and Schnabel (1976) and Teipel (1988) characterizes fine psychomotor behavior based on its small paths of motion and movements which do not require a high amount of effort but a high level of precision and speed. The whole body is not involved. To judge on the content validity of the MLS, its construction must be taken into account: The MLS is based on Fleishman's factor analytic studies (see e.g., 1954). As described in Section 7.2.2.2, twelve factors were hypothesized (e.g., Fleishman, 1953b; Fleishman & Hempel, 1954a, 1954b; Hempel & Fleishman, 1955) and a minimum of three tests constructed representing each of the twelve factors. A subsequent factor analysis confirmed the existence of the hypothesized factors in the, from the tests derived data. Hence, content validity is not guaranteed, as the tests were only constructed in order to represent the hypothesized factors. It was not started from a universe of psychomotor behaviors and a random sample drawn to be evoked by the test to be constructed. Thus, it cannot be expected that the test reflects either all or a representative set of psychomotor behaviors. It is further to be considered that not the complete test was administered, but only a short form. The factor "aiming" was, for example, not included.

Second, construct validity demonstrates the degree to which the test concords with the underlying theory. Neuwirth and Benesch (2004) report correlation coefficients between the variables (see Table 20) when testing healthy individuals with their right hand (Hamster, 1980b).

Table 20

Correlations Between the Variables of the Items Comprising the Applied Short Form of the MLS (Adapted From Neuwirth & Benesch, 2004)

	Aiming (TD[a])	Steadiness (M[b])	Steadiness (MD[c])	Line-tracing (M[b])	Line-tracing (MD[c])	Line-tracing (TD[a])	Tapping (HI[d])
Aiming (TD[a])	-						
Steadiness (M[b])	.21	-					
Steadiness (MD[c])	.18	.92	-				
Line-tracing (M[b])	.16	.48	.44	-			
Line-tracing (MD[c])	.20	.45	.46	.90	-		
Line-tracing (TD[a])	*.32*	-.17	-.16	-.24	-.24	-	
Tapping (HI[d])	-.18	-.12	-.11	-.23	-.28	-.03	-

Note. [a] TD = total duration. [b] M = number of mistakes. [c] MD = duration of the mistakes. [d] HI = number of hits.

The correlation matrix demonstrates that the variables used to calculate the four factors of interest (see Section 13.2.3) correlate highly (e.g., the duration of mistakes of the item "steadiness" correlates with the number of mistakes of the item "steadiness" to r = .92); whereas the variables not used to calculate a given factor only correlate to a small/medium degree with others used to calculate this factor (e.g., the number of mistakes of the item "steadiness" correlates with the total duration of the item “line-tracing” to r = -.17). This supports the assumption that independent factors of fine motor abilities are measured with the MLS.

A factor-analytic study has been conducted by Ringendahl (2002, see before), in which seven factors with an Eigenvalue bigger than one (Varimax-rotation) were extracted. These factors were termed “steadiness” (Factor 1), “speeded manual dexterity” (Factor 2), “movement planning” (Factor 3), “complex movement, left” (Factor 4), “complex movement, right” (Factor 5), “speeded finger dexterity” (Factor 6), “finger-tapping speed” (Factor 7). The factor-loading matrix is given in Table 21 (the items “long pegs”, “pursuit”, and “short pegs” have not been administered in this study).

Table 21

Results of the Factor Analysis Analyzing the Construct Validity of the MLS (Adapted From Ringendahl, 2002)

Variables		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
Steadiness	L, M[a]	.80	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	R, M[a]	.79	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	L, MD[b]	.76	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	R, MD[b]	.72	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Long pegs	L, TD[c]	n.a.	.77	n.a.	n.a.	n.a.	n.a.	n.a.
	R, TD[c]	n.a.	.88	n.a.	n.a.	n.a.	n.a.	n.a.
Aiming	L, TD[c]	n.a.	.75	n.a.	n.a.	n.a.	n.a.	n.a.
	R, TD[c]	n.a.	.56	n.a.	n.a.	.65	n.a.	n.a.
Pursuit	L, M[a]	n.a.	n.a.	-.89	n.a.	n.a.	n.a.	n.a.
	R, M[a]	n.a.	n.a.	-.83	n.a.	n.a.	n.a.	n.a.
	L, MD[b]	n.a.	n.a.	.59	n.a.	n.a.	n.a.	n.a.
	R, MD[b]	n.a.	n.a.	.60	n.a.	n.a.	n.a.	n.a.
Line-tracing	L, TD[c]	n.a.	n.a.	n.a.	.89	n.a.	n.a.	n.a.
	R, TD[c]	n.a.	n.a.	n.a.	n.a.	.65	n.a.	n.a.

	L, M[a]	n.a.	n.a.	n.a.	.77	n.a.	n.a.	n.a.
	R, M[a]	n.a.	n.a.	n.a.	n.a.	.73	n.a.	n.a.
	L, MD[b]	n.a.	n.a.	n.a.	.69	n.a.	n.a.	n.a.
	R, MD[b]	n.a.	n.a.	n.a.	n.a.	.60	n.a.	n.a.
Short pegs	L, TD[c]	n.a.	n.a.	n.a.	n.a.	n.a.	.74	n.a.
	R, TD[c]	n.a.	n.a.	n.a.	n.a.	n.a.	.80	n.a.
Tapp-ing	L, HI[d]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	R, HI[d]	n.a.	n.a	n.a.	n.a.	n.a.	n.a.	n.a.
% var.[e]		29.5%	12.6%	10.9%	7.7%	6.0%	5.2%	4.7%

Note. n.a. = not available. L = left hand. R = right hand.
[a] M = number of mistakes. [b] MD = duration of mistakes. [c] TD = total duration. [d] HI = number of hits. [e] % var. = % of total variance explained.

From a theoretical point of view, Ringendahl's (2002) steadiness factor resembles the definition of steadiness given by Neuwirth and Benesch (2004), the same is the case for the factors aiming and movement planning, precision of arm-hand movements and complex movements, hand/finger dexterity and speeded finger dexterity, velocity of arm-hand movements and speeded manual dexterity, as well as tapping and finger-tapping. This implies that the variables number of mistakes and duration of mistakes of the item "steadiness" should have high factor loadings on the factor steadiness, the variables number of mistakes and duration of mistakes of the item "line-tracing" on the factor complex movements, the variables total duration of the item "line-tracing" and the variable total duration of the item "aiming" on the factor speeded manual dexterity, and the hits of the item "tapping" on the factor tapping. The factor loadings introduced in Table 21 demonstrates these patterns with one exception: The variable total duration of the item "line-tracing" loads highly on Ringendahl's factor of complex movement.

Neuwirth and Benesch (2004) report a factor loading structure similar to the one given by Ringendahl (2002), which, however, does not depict the problem with the variable total duration of the item "line-tracing". The factor loading matrix given by Neuwirth and Benesch (2004) is used in order to calculate the values on the relevant factors (see Section 13.2.3).

Summarizing the results of the factor analyses and the correlation matrix, the factor structure defined by Fleishman (1954, 1972b) and Hempel and Fleishman (1955) is supported. Hence, it is assumed that the MLS represents the underlying model of Fleishman's (1954, 1972a) psychomotor abilities.

Third, the criterion validity refers to the relationship of the test results with external criteria. One such criterion is the handedness. The dominance of one hand, which researchers trace back to training effects (see e.g., Guldner, Mader, & Zeltner, 1980) should be detectable in the data of a fine motor test such as the MLS. Neuwirth and Benesch (2004) tested this research question. The results (352 participants, 173 male, 179 female, age range: 7-20 years) are given in Table 22.

Table 22

Means of the Test Results From the MLS for the Dominant and Indominant Hand and the Results of the Duncan Test Comparing the Means (Adapted From Neuwirth & Benesch, 2004)

Variables		Right hand			Left Hand		
		Right handed-participants	Left handed-participants	*p*	Right handed-participants	Left handed-participants	*p*
Steadi-ness	M[a]	13.84	22.43	**	25.12	13.60	**
	MD[b]	2.14	3.07	.14	3.16	1.46	**
Line-tracing	M[a]	31.20	45.26	**	41.37	28.10	**
	MD[b]	3.23	5.03	**	4.95	2.79	**
	TD[c]	40.56	44.79	.10	32.86	30.86	.35
Aiming	M[a]	.99	2.43	**	3.83	2.21	**
	HI[d]	19.86	19.60	.24	19.83	19.50	.43
	MD[b]	.02	.08	**	.21	.08	**
	TD[c]	10.05	10.66	.21	10.83	7.96	**
Tapping	HI1[e]	83.81	73.89	**	71.18	82.10	**

	HI2[f]	74.76	66.17	**	64.18	73.32	**
	HI[d]	158.58	140.06	**	135.37	155.4	**
Long pegs	TD[3]	41.30	44.43	*	46.56	39.44	**

Note. [a] M = number of mistakes. [b] MD = duration of mistakes. [c] TD = total duration. [d] HI = total number of hits. [e] HI1 = number of hits in the first half. [f] HI2 = number of hits in the second half.
$^{**}p < .01$. $^{*}p < .05$.

As Table 22 demonstrates, the expected differences between the dominant and the indominant hand are present for most variables and for participants who are right- and left-handed. For example, the means of the variable number of mistakes of the item "line-tracing" differ significantly for the right hand for the right- and left-handed participants.

Another study to test the criterion validity has been conducted by Hamster (1980b), who published significant differences between participants with contusio cerebri with and without neurological disorders (see also Section 13.2.5). Other studies, such as the ones conducted by Motomura (1994) or by Kraus, Klotz, Fischer, and Przuntek (1987), further confirm the criterion validity of the MLS.

13.2.6. Why This Test?

It has been chosen to work with the short form of the MLS from Sturm and Büssing (1985) because of two reasons:

First, the MLS measures the factors of relevance of the chosen setting for the study. Only fine psychomotor abilities are required to complete the gardening task. For example, filling a pot with soil requires a small path of motion (from the soil box to the pot in the seed box). Gross movements involving the whole body and requiring strength have been excluded from the study, also because of the special requirements of the population from which the sample is drawn (see Section 14).

Second, the quality measurements of the MLS yield promising results for a variety of populations (see Section 13.2.5). Not only healthy individuals have been tested but also individuals with various neurological disorders. For both populations the empirically derived quality factors are judged as sufficiently high. This is especially the case, as the validity of fine psychomotor tests has typically only been around $r = .20$ (Salvendy & Seymour, 1973).

13.3. Material Used to Measure the Dependent Variables

13.3.1. Description of the Eye Tracking System and the Setup Used

Generally speaking, the eye tracking system is used to determine the gaze position of its user, i.e., the point in the person's field of view he/she is currently looking at. In order to determine this gaze position, various technologies and methods can be used (see e.g., Duchowski, 2003; Young & Sheena, 1975). The eye tracker used in this study is a head-mounted dark pupil eye tracking system with a sampling rate of 50/60Hz, a tracking resolution of 0.1°, a gaze position accuracy of 0.5° to 1.0°, a tracking range of +/-30° in the horizontal and +/-25° in the vertical plain (SMI, 2004). The head unit weights 450gr and, as applied in this study, tracked the left eye of the participant. The system was developed by the company Senso-Motoric Instruments GmbH (www.smi.de).

Head-mounted dark pupil systems use an infra red sensitive camera, which is mounted on the head unit, in order to illuminate the eye via a transparent mirror. The eye reflects this illumination, while the pupil absorbs the infra red light. This reflection is fed back to the system again by the transparent mirror and sensed by the system. This mirror is also mounted on the head unit and has to be adjusted in front of the user's eye, which is tracked, so that the reflection can be processed. Appropriate algorithms are used to calculate the center of the pupil. To compensate shifts of the camera in relation to the user's head, the corneal reflex of the pupil is also tracked. A calibration procedure is required in order to relate the center of the pupil with a gaze position in the field of view (see Section 13.3.2).

The eye tracking system consists of a helmet the participants has to wear during the study, which is a commercial bicycle helmet, on which the required equipment is mounted, as well as the eye tracking PC (Windows 2000, Intel Pentium IV, 1600 MHz, Graphic Card Direct X Capable 32 MB) and a battery set used for the wireless radio transmission of the data from the head unit to the eye tracking PC. The small battery pack was mounted on the back of the wheelchair during the study, so that the participant was not affected while executing the gardening tasks. The cable from the helmet to the battery let the participants enough room for moving.

The output from the eye tracking system was a video from the scene camera containing the gaze cursor indicating where the participant looked at. This video also contained a time-stamped message in its upper left corner, which was used for calculating the durations of the gazes and the operations (see Section 13.3.2).

13.3.2. Eye Tracking Procedure

In a first step, the participants put on the helmet, which was then secured so that slip movements, which might have reduced the accuracy of the measurements were - as good as possible - avoided. Then, the eye camera and the mirror on the helmet were adjusted so that the participant's eye was visible directly in the center of the eye window of the eye tracking software. In this eye window, two crosshairs were visible: the first following the center of the pupil, the second following the corneal reflex. For some participants, thresholds needed to be adjusted so that both crosshairs continuously located the corneal reflex and the pupil while the participant moved his/her eyes in all directions. If the eye tracking system still showed difficulties with tracking the eye, the area of interest, in which the software tried to locate the center of the pupil and the corneal reflex, was adjusted to exclude artifacts (e.g., reflections of glasses) possibly distracting the software.

In a next step, the eye tracking system had to be calibrated. For this purpose, the participants were asked to fixate five targets distributed in the participant's field of vision. As targets, crosses on little pieces of paper were used, which were attached to a wall. As soon as the participants fixated the indicated cross and the experimenter pressed a key, the position of the eye was recorded by the system. It was decided to work with five targets, as then, the calibration procedure resulted in a sufficient overall accuracy without taking too much time.

The calibration was performed at a distance of about 1m in order to reach a minimum parallax error, which arises when the distance between the participant's eye and the calibration points are extremely different to the differences between the participant's eye and the points of interest later in the study. The calibration has further been executed in the same room in which the study took place, in order to reduce errors due to changing light conditions.

The success of the calibration was controlled by asking the participant to look at given landmarks in the room (which were not related to the objects required to execute the tasks in question) and by checking whether the gaze vector in the output video showed the accurate position.

Last, data recording was started. The output videos were recorded in the smallest resolution due to the sizes of the video files (with MPEG-1 VCD 352x288 with 25 Hz). The videos comprised the images of the scene camera, in which the gaze vector was inserted indicating the point the participant currently fixated. In order to be able to retrace the timing, the videos were time-stamped and the time was presented in the upper right corner of the video.

13.3.3. Analyses of the Eye Tracking Videos

The scene videos with the gaze vector and the time stamp were analyzed for each participant separately. Of interest were the goal position of the gaze vector and the current operation the participant was executing. To yield the variables required to test the stated hypotheses (see Section 12), the eye tracking videos were transliterated for each participant in two MS Excel sheets, the first containing the goal position of the gaze vector (for a list of possible goal positions, see Appendix I), the start and end dates of that gaze and its duration, the second containing the conducted operation (see Appendix E), its start and end dates and its duration. Regarding the operations, it was also noted, whether and when the operation was interrupted as well as the duration of an interruption. All durations were measured in 1/60 seconds.

Based on these MS Excel sheets, the following variables were calculated which were the basis for the ones with which the hypotheses testing was conducted (for a thorough description of these variables, see Section 12):

- total number of gazes for each task (in the analyses used as NG-T1-NG-T4 and applied to calculate DG-T1-DG-T4, NRG-T1-NRG-T4, DRG-T1-DRG-T4, DAG-T1-DAG-T4, NIG-T1-NIG-T4, and DIG-T1-DIG-T4)

- total duration of all gazes for each task (in the analyses used to calculate DG-T1-DG-T4, DRG-T1-DRG-T4, DAG-T1-DAG-T4, and DIG-T1-DIG-T4)
- total number of task-related gazes for each task (in the analyses used to calculate NRG-T1-NRG-T4, and DRG-T1-DRG-T4)
- total duration of task-related gazes for each task (in the analyses applied to calculate DRG-T1-DRG-T4)
- total number of plans (in the analyses used as NPL-T1-NPL-T4 and applied to calculate DPL-T1-DPL-T4)
- total duration of the plans (in the analyses applied to calculate DPL-T1-DPL-T4)
- total number of anchors looked at for each practice trial (in the analyses applied to calculate DAG-T1-DAG-T4)
- total duration of the gazes on anchors for each practice trial (in the analyses applied to calculate DAG-T1-DAG-T4)
- total number of the operation-independent gazes (in the analyses used to calculate NIG-T1-NIG-T4 and DIG-T1-DIG-T4)
- duration of the operation-independent gazes (in the analyses used to calculate DIG-T1-DIG-T4)
- total number of operations the target object for each practice trial was used (in the analyses used to calculate OR-T1-OR-T4)
- total number of operations for each practice trial (in the analyses used to calculate OR-T1-OR-T4)
- total duration of all gazes on the target object (in the analyses used to calculate DGO-T1-DGO-T4)
- total number of gazes on an object (in the analyses used to calculate DGO-T1-DGO-T4)
- total duration of all operations for each practice trial (used to calculate DO-T1-DO-T4 and DIO-T1-DIO-T4)
- total number of operations executed for each practice trial (used to calculate DO-T1-DO-T4, NIO-T1-NIO-T4, and DIO-T1-DIO-T4)

- total number of task-irrelevant operations for each practice trial (used to calculate NIO-T1-NIO-T4 and DIO-T1-DIO-T4)
- total duration of the task-irrelevant operations for each practice trial (used to calculate DIO-T1-DIO-T4)
- total number of strategic changes for each practice trial (in the analyses used as NST-T1-NST-T4)
- total number of executed actions (in the analyses used as NA-T1-NA-T4)

As the eye tracking videos might not display all information required especially for calculating NST-T1-NST-T4, the experimenter also wrote a protocol in which he/she put record on each action of the participant. This information was used as to complement the videos from the eye tracking system, in case the videos did not show the relevant sections.

13.4. Material Used to Measure the Control Variables

To gather data on the control variables (for a list, see Section 12), a biographical questionnaire was applied. More specifically, especially the experience with and the interest in agriculture and relevant personal data (e.g., age) were assessed. The biographical questionnaire (given in Appendix D) was filled in by the participants in the second session of the study, before the intelligence test was carried out.

14. Description of the Sample and the Sampling Procedure

The study took place at the vocational college of the Evangelische Stiftung Volmarstein (www.esv.de). To recruit the participants, the teachers of the vocational college informed those of their students, who relied on a wheelchair about the study, its purpose, and its course. To clarify open questions of the potential participants, a meeting was conducted, during which interested wheelchair users were informed about the general procedure of the study, its purpose and the experimenter was introduced. Questions about the study were answered. All wheelchair users interested in participation took part in the study.

A sample size of 16 participants resulted (but see Section 15.2.2): These participants were between 20 and 31 years old; whereas eight of them were women, eight were men. All participants were registered in vocational education at the Evangelische Stiftung Volmarstein: Three were still at the beginning, i.e., in their first year, while twelve were in the second, third, or fourth year. Seven participants were registered in the economics and administration courses, five participants learnt design of media and print, whereas another three participants were enrolled in metal engineering. The data acquired in the biographical questionnaire further indicates that eight participants were right-handed, and seven left-handed. Most of them were dependent on a wheelchair since they were about six years ago. Hence, the years having relied on a wheelchair varies between 11 and 23 years. The participants depend on their wheelchairs because of various disabilities: The majority (i.e., eight participants) received the diagnosis spasticity, six participants suffered from spina bifida, one participant were diagnosed with dysmelia and one further participant was paralyzed incompletely. A summary of these major descriptive statistics describing the sample is given in Table 23.

Table 23

Descriptive Statistics of the Relevant Characteristics of the Participants

	N	Minimum	Maximum	Mean	Median	*SD*
Year of vocational education	15	1	4	2.13	2	0.92
Age	15	20	31	23.38	23	2.55
Sex[a]	15	0	1	-	0	-
Handedness[b]	15	0	1	-	0	-
Years having used a wheelchair	15	11	23	17.43	17	3.23
Disability[c]	15	1	4	-	1	-
Type of vocational education[d]	15	0	2	-	0	-

Note. For the variables with only ordinal scale level, the mean and *SD* values are not displayed.

[a] 0 = male; 1 = female. [b] 0 = right-handedness; 1 = left-handedness. [c] 1 = spasticity; 2 = spina bifida; 3 = dysmelia; 4 = incomplete paralysis. [d] 0 = economy and administration; 1 = design of media and print; 2 = metal engineering.

15. Data Analysis

15.1. Analytic Strategy

In order to test the stated hypotheses (see Section 9), a four step procedure has been taken to ensure the quality and the reliability of the results:

In a first step, descriptive statistics (i.e., means, medians, standard deviations, maximum and minimum values as well as correlations) were analyzed to descriptively examine whether the expected relationships can be found in the data. As repeated measurement effects are of interest for most hypotheses, it is expected that adjacent trials correlate to a greater degree than do non-adjacent trials (Guttman, 1954). Also, the means, medians, minimum and maximum values are expected to change according to a typical pattern as stated in the hypotheses.

In a second step, the hypotheses were tested based on inferential statistics: General linear model analyses were applied with repeated measurements for most hypotheses except the statistics applied to test H^{I}_{10}. For the latter, general linear model analyses were applied without repeated measurements (for details, see Section 15.3.1.2).

As indicated by the hypotheses (see Section 9), two types of effects can be distinguished: repeated measurement effects of the dependent variables and two-way interaction effects between the repeated measurement effects of the dependent variables and the ability measures. The variables mirroring the relevant individual differences were included as independent variables in the inferential statistics applied; whereas only one independent variable was included in each analysis. This procedure has been taken due to the small sample size and resulting low power of the study. When including all independent variables of interest in one analysis, it would have been hardly possible to detect a, in the real world possibly existing effect. The results of these general linear model analyses (i.e., df_s, df_e, the values of the F-statistic, the levels of significance, and the partial effect sizes f^2) are given in the Sections 15.3.1.2 and 15.3.2.2 and interpreted. The partial effect sizes have also been adjusted in order to balance problems with the sums of squares, the calculations of the partial effect sizes are based on (see e.g., Hays, 1994; Völkle, Ackerman, & Wittmann, 2007). In order to derive an unbiased estimate of the partial effect size in the population (ε^2), the correction formula proposed by Kelley (1935) has been adjusted to the repeated measurement design at hand (see Equation 4).

$$\varepsilon^2 = \frac{SS_{source} - df_{error} * MS_{error}}{SS_{source} + SS_{error}} \tag{4}$$

SS_{source} = Sums of squares of the source

SS_{error} = Sums of squares of the error

MS_{error} = Means squares of the error

To define the shape and the direction of the significant effects, the results of the polynominal tests of linear, quadratic and cubic order are further introduced, as are figures visually demonstrating the significant effects. If the two-way interaction effects were not significant, the general linear model analyses were repeated only testing the repeated measurement effect of the dependent variable of interest. This procedure was also applied because of the low sample size: If the independent variables and their interaction with the dependent variables did not account for a significant portion of the dependent variable's variance, their inclusion reduced the degrees of freedom, which made it more difficult to detect a – possibly existing - effect only of the repeated measurements. The results of these single repeated measurement analyses are also introduced and discussed, as are, if the repeated measurements are significant, the results of the polynominal tests of linear, quadratic and cubic order and according figures.

Control variables were included in the analyses to account for additional variance. If the results revealed that a control variable only marginally explained variance of the dependent variable, this control variable was excluded from the analyses in order not to – unnecessarily - reduce the degrees of freedom.

The third step comprises testing the assumptions underlying the least-squares procedure of the *F*-distribution the general linear model makes use of. These assumptions, how they can be detected and what needs to be done in case they are violated are discussed in the following (according to Cohen, Cohen, West, & Aiken, 2003):

- There should be no measurement error in the independent variable. In order to check the reliability of the variables involved, a reliability analysis is performed for the eye tracking data (see Section 15.2.1). Regarding the independent variables, which are those measuring intelligence and psychomotor abilities, reliability coefficients are given when discussing the tests which were applied (see Sections 13.1.5.2 and 13.2.5.2).
- The variance of the residuals should be constant. This homoscedasticity means that for any value of the independent variables, the variance of the residuals should be constant. If the variances are not constant, this is termed *heteroscedasticity*. In order to detect heteroscedasticity, a scatterplot plotting the residuals against each independent variable and the predicted values were analyzed. Heteroscedasticity was diagnosed, if the scatterplots showed special effects such as triangles. To further support the results, the Mauchly-Test was applied. If this test yields a significant result, the sphericity assumption or the homogeneity of the residuals' variances is violated. If sphericity is in the data set, the results of the inferential statistics should be adjusted according to the conservative Greenhouse-Geisser (G-G) or the more liberal Huyn-Feldt (H-F) formulas.
- The residuals should be independent from each other and, thus, not correlated. Repeated measurement designs often violate this assumption, as the observations are not independent from each other, so that adjacent trials correlate to a greater degree than non-adjacent trials. These systematic dependencies between the residuals appear in scatterplots showing the residuals on one axis and the ordered values on the other axis. A test for this assumption is e.g., the Durbin Watson Test.
- The residuals should be distributed normally. However, according to Kirby (1993) and Cohen and Cohen (1983), *F*-Tests are also robust towards the violation of this assumption. Again, the graphical check of the plot of

residuals is analyzed. Ideally, the residuals should be spread all over the possible range.

Generally speaking, the *F*-test is robust (Cohen & Cohen, 1983; Scheffé, 1959), so that if these assumptions are slightly violated, the validity of the analyses' results is still given.

After having tested the assumptions underlying the inferential statistics, the stability of the results were analyzed in a last step. This is especially important due to the small sample size. The results' stability can be violated because of multicollinearity, suppressor effects, and irregularities in the sample:

- Multicollinearity results when an independent variable can nearly perfectly be predicted from another one or a combination of other independent variables. To detect multicollinearity, the correlations were analyzed. The results of the inferential statistics must be interpreted with caution, when correlations between the independent variables are greater than $r = .90$. Another approach to detect multicollinearity is to calculate regression analyses in which each independent variable is predicted by the other remaining independent variables. This approach was not taken, as the number of independent variables included in one analyses will not be high, so that it is expected that the correlations will reveal multicollinearity, in case it is there.
- A suppressor effect occurs when one independent variable (i.e., the suppressor variable) correlates highly with another independent variable and when the suppressor variable does not significantly correlate with the dependent variable. The suppressor variable then suppresses the variance of the other independent variable, so that the contribution of the independent variable regarding the prediction of the dependent variable is increased and over-estimated. Suppressor effects can also be detected based on the regression analyses in which each independent variable is predicted by the other independent variables or by checking the correlation matrix. Due to the same reason as already mentioned regarding multicollinearity, only the correlation matrices were analyzed to detect suppressor effects.

- Last, irregularities in the sample can influence the results of the inferential statistics. Two procedures have been performed in order to ensure that irregularities in the sample did not endanger the results' stability. This is especially important due to the small sample size. First, boxplots were analyzed to detect outliers. Second, the general linear model analyses were repeated for the significant effects, each time one participant has been excluded from the analyses. The standard deviation of these partial effect sizes of the different analyses indicates the stability of the results. If the standard deviation is high, it shows that a participant might have had a big impact on the study's results. Hence, stability is not given. These partial sizes cannot be compared with the original ones due to the reduced sample size.

Before these four steps can be executed, the reliability of the variables depending on the eye tracking data is analyzed, missing data will be discussed and the final control variables will be calculated.

15.2. Pre-Analyses

15.2.1. Reliability Analyses

Reliability refers to the formal accuracy of measurements and the derived data. For the tests applied to measure the individual characteristic of the intelligence factors and the psychomotor abilities, the reliabilities were given in the according sections, in which the applied tests were introduced (see Section 13.1.5.2 for the variables based on the BIS-4 and Section 13.2.5.2 for the variables based on the MLS). The analyses discussed here proof the reliability of the variables derived from the eye tracking procedure, i.e., the variables measuring the changes of the information acquisition and behavior. In order to yield a measurement of their reliabilities, two analyses have been performed:

First, the reliability of the identification of the objects looked at and of the operations executed has been controlled by analyzing the videos from the eye tracking system twice for one participant. The second analysis has been performed by an independent researcher. The objects looked at and the operations executed defined by the first and second analysis show no deviation.

Second, the reliability of the duration of the gazes on the objects and of the operations executed has been calculated. For this purpose, the start dates and end dates of each gaze on each object and of each operation have been determined twice for one participant from two independent researchers. For both analyses, the durations of the gazes and the operations were calculated and the results were correlated. The first and second analyses of the duration of the operations correlate with $r = .99$ ($N = 553$, $p < .01$); while the first and second analyses of the duration of the gazes correlate as well with $r = .99$ ($N = 508$, $p < .01$).

The final variables, with which the hypotheses have been tested and which were based on the eye tracking data and introduced in Section 12., were derived from an aggregation of either the durations of the gaze or the operations or the number of the identified objects looked at or the identified operations executed. It is expected that the reliability of these final variables is not reduced compared to the reliability coefficients introduced here, as data aggregation results in an increase in reliability (see e.g., Asendorpf, 1999; Steyer & Eid, 1993). Hence, the derived reliability coefficients can be regarded as good and it was acted on the assumption that the variables based on the eye tracking data are reliable.

15.2.2. Missing Data

Missing data occurred in three aspects:

First, missing data arose due to problems with the eye tracking system: No data was transferred to the stationed PC for two participants, so that information neither about their gazes nor about their operations was available. Hence, these two participants were excluded from the analyses. For another three participants, the gaze vector could not be determined reliably by the eye tracking system due to visual disorders affecting the eye movements/fixations. Hence, no information regarding the gaze behavior is available, but information on their operations was at hand for statistical evaluation.

Second, one participant got ill during the course of the study, so that he could not participate in the second session. Hence, what was missing were his results from the intelligence test and his answers on the questions in the biographical questionnaire. These missing data were substituted with the averages of the according variables derived from the other participants. Another participant did only participate in the second session of the study, as he did not consent to participation in the first session. This participant was excluded from the analyses.

Summarizing, from the original 16 participants, data from 10 participants were at hand for statistically evaluating the gaze behavior, data from 13 participants were available for analyzing the operations, and 15 participants executed the psychomotor test, the intelligent test and answered the biographical questionnaire. The missing data regarding the intelligence tests and the biographical questionnaire were substituted by the means of the appropriate variable. According to Section 10, the reported missing data will have the consequence that only large effects can be detected.

Third, not all participants answered all questions in the biographical questionnaire used for gathering data on the control variables. Regarding age, experience in agriculture, number of years depending on a wheelchair, interest in agriculture, last school leaving certificate, type of disability, type of vocational education, and number of years in vocational education data were not available for all participants (for a summary of the number of missing data, see Table 24). Regarding age, experience in agriculture, number of years having been dependent on a wheelchair, interest in agriculture, last school leaving certificate, and type of disability the missing data were replaced by the mean of the according variable, as was the missing data regarding the type of vocational education. The number of years in vocational education were substituted based on the average number of years within that field of vocational education. This approach was taken as the number of years in vocational education was closely related to the field of vocational education the participants were enrolled in.

Table 24

Summary of the Number of Missing Data Regarding the Biographical Questionnaire

Variable	A	B	C	D	E	F	G	H
Number of missing data	2	1	2	1	1	3	2	2

Note. A = age. B = experience in agriculture. C = number of years using a wheelchair. D = interest in agriculture. E = last school leaving certificate. F = type of disability. G = type of vocational education. H = number of years in vocational education.

15.2.3. Aggregation of the Control Variables

The control variables which might account for variance of the dependent variables but are not of interest for this study were surveyed in the biographical questionnaire (see Section 12 and Appendix D). More specifically, the participants' age, sex, handedness, type of disability, type of wheelchair used (i.e., manually or electrically powered), number of years having relied on a wheelchair, interest in agriculture, experience in agriculture, last school leaving certificate, field of vocational education, number of years enrolled in vocational education, degree of disability, and the characteristics of the disability according to their handicapped ID were assessed. As three of these variables (i.e., the characteristics of the disability according to the handicapped ID, the type of wheelchair, and the degree of disability) hardly varied, these variables were excluded from the following analyses.

As the sample size used for testing the hypotheses is relatively small, it was aimed at reducing the number of control variables included in the statistical evaluation, so that the degrees of freedom were not unnecessarily reduced. For this purpose, an aggregation of the control variables was performed based on the correlation matrix as given in Table 25.

Table 25

Correlations Between the Control Variables

	1	2	3	4	5	6	7	8	9	10
1	-									
2	.23	-								
3	$.53^{*}$	-.20	-							
4	-.12	.05	-.16	-						
5	.07	.18	-.18	.16	-					
6	-.15	.06	-.34	$.67^{**}$	$.62^{*}$	-				
7	.24	.44	.01	.39	.40	.45	-			

8	-.18	.44	-.22	.04	.31	.16	.25	-		
9	.01	.25	-.08	-.23	.57*	.18	.57*	.27	-	
10	.49	-.41	.47	-.03	-.18	-.21	.01	-.61*	-.26	-

Note. 1 = age. 2 = sex. 3 = handedness. 4 = type of disability. 5 = last school leaving certificate. 6 = field of vocational education. 7 = year of vocational education. 8 = interest in agriculture. 9 = experience in agriculture. 10 = number of years, the wheelchair has been required.

* $p < 0.05$; two-sided. ** $p < 0.01$; two-sided.

Due to the correlation patterns, two aggregates of control variables were established:

The first bundle of variables includes the participants' age, sex, and handedness. The correlation between the participants' age and handedness was significant ($r = .53$, $p < .05$). Sex was also included in that first aggregate, as the variable showed relatively high correlations with both variables ($r_{age,sex} = .23$, $r_{sex,handedness} = -.20$), which, however, did not reach the level of significance. In order to aggregate these three variables, they were *z*-standardized in a first step and added in a second step. The resulting aggregated control variable (CV1) was used in some of the inferential tests applied (see Section 15) for controlling the dependent variables' variance.

As Table 25 further indicates, experience in agriculture correlates significantly with the last school leaving certificate ($r = .57$, $p < .05$) and with the year being enrolled in vocational education ($r = .57$, $p < .05$). Both correlations could be explained based on the field of vocational education chosen, as not all fields of vocational education can be selected with any school leaving certificate. Besides, some fields of vocational education require more years of training, so that a bias can be expected. The field of vocational education depends, of course, not only on personal interests but also on the capabilities of the wheelchair users and their disability. This explains the highly significant correlation between the field of vocational education and the disability of the participants ($r = .67$, $p < .01$). Another significant correlation was found between the interest in agriculture and the number of years, the wheelchair has been required by the participants ($r = -.61$, $p < .05$). It is also expected that this effect is an indirect one, as wheelchair users are handicapped in executing agricultural tasks (e.g., due to the necessity to drive through muddy grounds). The interest and the experience in agriculture are not significantly correlated (r = .27), but it is expected that these variables are theoretically related. Hence, the z-standardized variables of experience in agriculture, the number of years the wheelchair has been relied on, the interest in agriculture, the last school leaving certificate, the type of disability, the type of vocational education chosen, and the number of years enrolled in vocational education were summed and constitute the second aggregate of control variables (CV2).

15.3. Hypotheses Testing

In the following, the analyses executed to reach well-grounded results (for a description of the analytic strategy, see Section 15.1) on the hypotheses are introduced.

15.3.1. Does the Gaze Behavior Change According to the Proposed Theory and Does This Change Interact With the Ability Measures?

The hypotheses testing the proposed changes of the information acquisition while adapting to a new situation and its interaction with the ability measures (see Section 9) will be analyzed. According to the analytic strategy proposed in Section 15.1, first, the descriptive analyses will be given, second the inferential statistics and their results will be discussed and third, the assumptions underlying the test statistics and the stability of the results will be analyzed. Last, conclusions will be given.

15.3.1.1. Descriptive analyses.

The descriptive analysis will allow valuable insights in whether the expected effects are actually there and in whether the effects go in the anticipated direction. For this purpose, basic statistics and correlations are discussed in the following sections.

15.3.1.1.1. Basic statistics

To discuss the existence of the, in the hypotheses expected effects, the means, medians, standard deviations, minimum and maximum values as well as the number of participants for whom data are available for the independent and dependent variables of interest are introduced in a first step of the descriptive analyses (see Table 26 and Table 27).

As indicated in Table 26 and Table 27, data are available from 10 to 16 participants. This difference occurred due to problems with transferring valid eye tracking data and due to one participant, who did not consent in participation in the study's first session (for an explanation of the missing data, see Section 15.2.2).

The descriptive statistics of the dependent variables, displayed in Table 26, especially their means and standard deviations indicate a typical pattern, if their expected repeated measurement effects are in the data set. For example, the means and medians of NG (included in the analyses testing H^{I}_{1}) show a clear decline in their magnitude with the number of practice trials performed, as do their minimum and maximum values. Such a general, declining pattern is not only at hand for NG, but also for the following variables:

- DG (included in the analyses testing H^{I}_{2})
- DPL (included in the analyses testing H^{I}_{6})
- DAG (included in the analyses testing H^{I}_{7})
- NIG (included in the analyses testing H^{I}_{8})
- SDG (included in the analyses testing H^{I}_{11})

Other variables show an initial increase but later decrease in their magnitude of their means, medians, minimum and maximum values. This inverted "u"-shaped course is at hand for the following variables:

- NRG (included in the analyses testing H^{I}_{3})
- DRG (included in the analyses testing H^{I}_{4})
- NPL (included in the analyses testing H^{I}_{5})

Exactly the opposite course is demonstrated by the variable DIG (included in the analyses testing H^{I}_{9}): DIG decreases initially, but then increases again. The dependent variable, which has not yet been analyzed, is, DGO, which remains at about the same level overall trials. Considering also the standard deviation, the shape of the different means overall four practice trials can also be considered as an inverted "u". However, H^{I}_{9} does not propose a repeated measurement effect, but that DIG can be predicted significantly by OR at the end of the adaptation process. Hence, the means of both variables (see Table 26 and Table 27) should show a converging tendency, which is, however, not indicated in the data, as the means of OR and DIG are already quite similar for the initial trials.

Table 26

Descriptive Statistics of the Dependent Variables Reflecting the Change of the Gaze Behavior

	N	Mean	Median	*SD*	Minimum	Maximum
NG-T1	10	190.20	193.50	33.14	149.00	243.00
NG-T2	10	160.50	156.00	43.37	102.00	232.00
NG-T3	10	155.20	154.00	42.39	86.00	223.00
NG-T4	10	135.20	124.00	38.79	92.00	227.00
DG-T1	10	213.48	219.66	43.89	144.68	301.61
DG-T2	10	197.37	202.44	52.36	119.90	300.26
DG-T3	10	214.53	209.61	47.73	144.37	296.41
DG-T4	10	204.68	202.80	49.76	142.69	298.92
NRG-T1	10	0.17	0.16	0.05	0.09	0.25
NRG-T2	10	0.88	0.88	0.04	0.82	0.95
NRG-T3	10	0.10	0.09	0.05	0.04	0.19
NRG-T4	10	0.10	0.06	0.08	0.01	0.25
DRG-T1	10	0.96	0.89	0.33	0.60	1.62
DRG-T2	10	1.14	1.13	0.05	1.05	1.22
DRG-T3	10	1.01	1.00	0.04	0.93	1.07
DRG-T4	10	0.88	0.97	0.31	0.01	1.09
NPL-T1	10	6.40	6.50	4.25	0.00	13.00
NPL-T2	10	7.10	6.00	5.40	0.00	17.00
NPL-T3	10	5.80	4.00	4.44	1.00	14.00
NPL-T4	10	4.10	3.00	4.91	0.00	17.00
DPL-T1	10	195.11	163.25	175.62	0.00	611.33
DPL-T2	10	143.64	166.12	68.04	0.00	209.00
DPL-T3	10	161.39	130.05	97.99	59.60	389.29

DPL-T4	10	124.23	95.20	115.86	0.00	359.33
DAG-T1	10	166.78	152.42	138.76	-16.31	381.78
DAG-T2	10	84.07	82.23	90.11	-60.45	253.32
DAG-T3	10	63.08	35.53	127.37	-127.13	296.96
DAG-T4	10	107.79	94.06	181.87	-186.92	484.53
NIG-T1	10	0.20	0.22	0.05	0.11	0.26
NIG-T2	10	0.17	0.17	0.07	0.09	0.26
NIG-T3	10	0.13	0.13	0.06	0.03	0.21
NIG-T4	10	0.12	0.11	0.05	0.04	0.20
DIG-T1	10	0.65	0.62	0.21	0.37	1.08
DIG-T2	10	0.37	0.42	0.33	0.00	0.99
DIG-T3	10	0.53	0.52	0.14	0.36	0.75
DIG-T4	10	0.56	0.51	0.19	0.39	1.03
DGO-T1	10	0.08	0.08	0.03	0.04	0.16
DGO-T2	10	0.18	0.17	0.07	0.09	0.32
DGO-T3	10	0.11	0.11	0.03	0.08	0.16
DGO-T4	10	0.08	0.08	0.03	0.04	0.10
SDG-T1	10	66.13	-3.01	228.29	-27.99	713.28
SDG-T2	10	-1.94	-1.03	18.80	-30.61	21.80
SDG-T3	10	-11.44	-4.49	29.76	-72.36	21.09
SDG-T4	10	-4.31	-3.94	18.15	-34.26	35.46

In Table 27, not only the descriptive statistics for OR are given, but also the ones for the independent variables reflecting individual differences in the measured intelligence and psychomotor factors. Regarding the intelligence factors (K, B, M, V, N, and F), the data have a standard deviation, which is smaller than the one of the norm population except for B (SD_B = 10.44). Such a difference to the norm population is also at hand regarding the means: The intelligence factors' means of the current sample are lower than the ones of the norm population. However, as mentioned in Section 13.1, the procedures applied to gather the data at hand and the data, on which the norms are based, cannot be compared due to the implemented adjustments taken in order to meet the special requirements of the current sample.

In contrast to the intelligence data, the psychomotor factors (i.e., PR, ST, VE, and TP) have a relatively big standard deviation varying between SD_{ST} = 17.05 and SD_{PR} = 13.59. A reason could be the unequal degrees and types of disabilities and associated psychomotor deficiencies. A comparison to available norm populations was not made. As discussed in Section 13.2.4, first, the testing procedure was slightly changed to the strictly standardized administration procedure approved in the test's handbook due to the special requirements of the current sample and second, no norms were available e.g., for the population diagnosed with spasticity.

Table 27

Descriptive Statistics of the Independent Variables

Variables	*N*	Mean	Median	*SD*	Minimum	Maximum
OR-T1	13	0.05	0.05	0.02	0.00	0.08
OR-T2	13	016	0.14	0.04	0.12	0.26
OR-T3	13	0.06	0.06	0.02	0.04	0.12
OR-T4	13	0.07	0.07	0.02	0.03	0.11
K	16	87.68	85.50	6.77	79.90	101.90
B	16	85.43	84.95	10.44	71.40	107.30
M	16	84.08	84.15	6.98	74.50	102.30
V	16	86.71	84.10	8.30	74.10	102.30
N	16	86.14	86.30	6.66	74.40	99.60
F	16	84.86	84.00	7.46	75.00	98.80
ST	15	54.34	48.50	17.05	31.50	98.00
PR	15	49.25	47.50	13.59	25.00	71.00
VE	15	41.41	42.50	16.88	23.00	71.00
TP	15	47.13	42.50	16.63	23.00	71.00

15.3.1.1.2. Correlations

In a second step of the descriptive analyses, the correlations were analyzed, as especially repeated measurement effects cause a typical pattern of the correlations:

Adjacent trials correlate to a greater degree than do non-adjacent trials, if an effect of the repeated measurements is at hand. This ordered relationship between correlated variables has been termed *simplex pattern of correlations* and has been introduced by Guttman (1954). In the following, the correlations between the variables included in each analysis testing a given hypothesis are discussed.

Correlations between the variables involved when testing the, in H^I_1 expected effects

The correlations between NG and the intelligence factors are presented in Appendix J (Table J1). The typical ordered relationship between the repeated measurements of NG is apparent supporting the previously discussed changes of the means, medians, minimum and maximum values of NG: While NG-T2 and NG-T3 correlate to $r = .74$ ($p < .05$), NG-T1 correlates with NG-T4 only to $r = .27$ (n.s.). However, the pattern is not ideal, as NG-T1 and NG-T2 only correlate to $r = .24$ (n.s.). The correlations given in Table J1 further indicate a negative relationship between NG and the intelligence factors, meaning that more intelligent participants executed a smaller total number of gazes while practicing the gardening tasks compared to less intelligent participants. These correlations follow an inverted "u"-shaped course: B, for example, correlates with NG-T1 to $r = -.34$ (n.s.), with NG-T2 to $r = -.90$ ($p < .01$) and with NG-T4 to $r = -.54$. Hence, after an initial increase of the relationship, the correlations decrease again.

Correlations between the variables involved when testing the, in H^I_2 expected effects

Appendix J (Table J2) gives the correlations for all variables involved in the inferential statistics applied to test H^I_2. The correlations of the repeated measurements of DG do not mark a clear simplex pattern, but e.g., DG-T2 correlates to a greater degree with DG-T3 ($r = .73$, $p < .05$) than with DG-T4 ($r = .27$, n.s.). Parallel to the correlations between NG and the intelligence factors (see Table J1), the correlations between DG and K, B, M, V, N, and F are negative, so that the participants with lower intelligence values show a greater average gaze duration. The strength of this relationship changes for some of the intelligence factors: Regarding B, the correlations decrease with the number of practice trials performed; while the correlations between DG and K follow an inverted "u"-shaped course: DG-T1 correlates with K to $r = -.73$ ($p < .01$), DG-T2 with K to $r = -.13$ and DG-T4 with K to $r = -.81$.

<u>Correlations between the variables involved when testing the, in H^I_3 expected effects</u>

H^I_3 expects a repeated measurement effect of NRG overall four practice trials and an interaction of NRG with the intelligence factors. The descriptive statistics given in Table 26 do not show a clear pattern regarding a possible change of the variable with the number of practice trials performed. The same is the case regarding the correlations of the four practice trials of NRG (see Appendix J, Table J3): NRG-T4 correlates highly with NRG-T3 ($r = .70$, $p < .05$), but NRG-T2 only correlates to $r = -.26$ with NRG-T3 (n.s.).

<u>Correlations between the variables involved when testing the, in H^I_4 expected effects</u>

Another effect has been proposed regarding the repeated measurements of DRG and its interaction with the intelligence factors (see H^I_4). However, the correlations given in Table J4 (Appendix J), do not show a simplex pattern typical for repeated measurement effects. The non-adjacent trials correlate to a greater degree than the adjacent trials. For example, DRG-T1 correlates with DRG-T3 to $r = -.48$ (n.s.) but DRG-T1 correlates with DRG-T2 to $r = .14$ (n.s.). The correlational relationship between the intelligence factors and DRG tends to decline overall practice trials: While the correlations with the initial trials are positive, they are negative for the later trials. For example, M correlates with DRG-T1 to $r = .27$ (n.s.); whereas DRG-T4 correlates with M to $r = -.31$ (n.s.).

<u>Correlations between the variables involved when testing the, in H^I_5 expected effects</u>

A repeated measurement effect of NPL and its interaction with the intelligence factors is expected in H^I_5. The correlations of the involved variables are given in Table J5 (Appendix J) and show an ambiguous picture about the existence of the repeated measurements of NPL. While the repeated measurements of NPL correlate generally speaking to a great degree with each other, a simplex pattern is not clearly indicated: While NPL-T3 correlates with NPL-T4 to $r = .70$ ($p < .01$), NPL-T1 correlates with NPL-T3 to $r = -.84$ ($p < .01$). The correlations between NPL and the intelligence factors are generally speaking negative, i.e., the more intelligent the participants are, the less plans were formulated. Only K showed a general change overall practice trials of NPL: the correlations increased.

Correlations between the variables involved when testing the, in H^I_6 expected effects

The analyses applied to test the, in H^I_6 expected effects comprised the repeated measurements of DPL and the intelligence factors respectively. Again, the correlations between these variables introduced in Table J6 (Appendix J) only give a diffuse picture: Some non-adjacent trials (e.g., $r_{DPL\text{-}T2,DPL\text{-}T4} = .63$, n.s.) correlate to a greater extent than the adjacent trials (e.g., $r_{DPL\text{-}T1,DPL\text{-}T2} = .30$, n.s.). The same is the case regarding the correlations between the repeated measurements and the intelligence factors: While all correlations are negative (i.e., the more intelligent the participant is, the shorter was the duration of the formulated plans), a general tendency could not be identified: the correlations between DPL and B tend to increase, while N and V show a "u"-shaped change of the correlations with DPL.

Correlations between the variables involved when testing the, in H^I_7 expected effects

The correlations between the variables included in the analyses testing the repeated measurement effect of DAG and its interaction with the intelligence factors (H^I_7) are introduced in Table J7 (Appendix J). These correlations already give important insights in a possible repeated measurement effects: The adjacent trials correlate quite highly (e.g., $r_{DAG\text{-}T1,\ DAG\text{-}T2} = .46$, n.s.), while non-adjacent trials correlate to a lesser degree (e.g., $r_{DAG\text{-}T1,\ DAG\text{-}T3} = .12$, n.s.). However, DAG-T2 and DAG-T4 correlate to $r = -.40$ (n.s.). Hence, a consistent simplex pattern is not in the data set. The correlations with the intelligence factors show the following pattern: Correlations with the initial and final trials are relatively small; whereas the middle trials correlate to a bigger extent with the intelligence factors.

Correlations between the variables involved when testing the, in H^I_8 expected effects

Table J8 in Appendix J gives the correlations between the variables included in the analyses testing the effects proposed in H^I_8, which are the repeated measurements of NIG and the psychomotor abilities. The correlations between the repeated measurements reveal a simplex pattern supporting the expected effect: While the first and second trial correlate to $r = .81$ ($p < .01$), the first and third trials only show a correlational relationship of $r = .30$ (n.s.). The correlations between NIG and the psychomotor abilities tend to decline with the number of practice trials performed. For example, the correlations between NIG and PR are positive for the first trials and negative for the final trials.

Correlations between the variables involved when testing the, in H^I_9 expected effects

H^I_9 expects a repeated measurement effect of DIG and an interaction of this effect with the psychomotor abilities. The correlational pattern between the variables involved is introduced in Table J9 (Appendix J) and only give first indications and do not show the – for repeated measurement effects – typical simplex structure. The first practice trials hardly correlate at all with the other practice trials (e.g., $r_{DIG-T1,\ DIG-T2} = .00$, n.s.); while the other practice trials generally speaking correlate to a great extent with each other.

Correlations between the variables involved when testing the, in H^I_{10} expected effects

The correlations between OR and DGO, which are of interest when testing the effects proposed H^I_{10}, are given in Table J10 (Appendix J). As H^I_{10} states, it is expected that with the number of practice trials, OR is becoming a better predictor for DGO. The correlational pattern, however, do not show a clear pattern: While the correlation between the first trial is $r_{OR-T1,DGO-T1} = .32$ (n.s.), the correlation for the last trial reaches to $r_{OR-T4,DGO-T4} = .71$ ($p < .05$). However, that increase, supporting the hypothesized effect is not consistent. The correlations decrease between the second and third practice trial.

Correlations between the variables involved when testing the, in H^I_{11} expected effects

The last hypothesis, H^I_{11}, expects a repeated measurement effect of SDG as well as an interaction of this effect with the measured intelligence factors. A repeated measurement effect of SDG cannot clearly be identified when analyzing the correlations between the involved variables given in Table J11 (Appendix J): The adjacent trials do not correlate higher than the non-adjacent trials.

Summary of the correlations between the variables involved in the tests

The correlations between the repeated measurements of the various dependent variables and with the variables reflecting the individual differences in the participants' abilities do not show a clear and consistent picture. For some relationships, a simplex pattern indicating a repeated measurement effect can be identified quite clearly (e.g., NG), for others, the adjacent trials correlate even to a smaller degree than the non-adjacent trials (e.g., DRG). The inferential statistics applied in Section 15.3.1.2 will give further indications on the existence and size of the expected effects.

15.3.1.2. Inferential analyses.

The inferential statistics were applied in order to test the in Section 9 stated hypotheses and the, in Section 15.3.1.1 descriptively discussed and potentially existing effects.

Inferential analyses testing the, in H^I_1 expected effects

In order to statistically evaluate the, in H^I_1 proposed effect of the repeated measurements of NG and its interaction with the measured intelligence factors, six general linear model analyses were performed with NG-T1, NG-T2, NG-T3, and NG-T4 as dependent variables and with the intelligence factors as independent variables. It has been decided to test the two-way interaction effects of the repeated measurements with intelligence in separate analyses and, thus, only one intelligence factor was included in each analysis performed. This procedure has been taken due to the small sample size and resulting limited power of the study at hand (see also Section 10 and 15.1). As CV1 and CV2 did not account for a significant part of the variance of the dependent measures at hand, they were not included in these analyses. The results of the general linear model analyses are given in Table 28.

Table 28

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NG and its Interaction With the Intelligence Factors as Expected in H^I_1

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				
NG	3	24	1.07	.38	.38	.38	0.12	0.01

NGxK	3	24	1.20	.33	.33	.33	0.13	0.02
NG	3	24	1.41	.27	.27	.27	0.15	0.04
NGxB	3	24	1.69	.20	.20	.20	0.17	0.07
NG	3	24	0.61	.61	.59	.61	0.07	0.00
NGxM	3	24	0.53	.67	.64	.67	0.06	0.00
NG	3	24	1.51	.24	.24	.24	0.16	0.05
NGxV	3	24	1.68	.20	.21	.20	0.17	0.07
NG	3	24	0.76	.53	.51	.46	0.09	0.00
NGxN	3	24	0.89	.46	.45	.46	0.10	0.00
NG	3	24	0.55	.66	.63	.67	0.06	0.00
NGxF	3	24	0.60	.62	.60	.62	0.07	0.00

As the *p*-values in Table 28 demonstrate neither the repeated measurement effect of NG nor its interaction with the intelligence factors reach the level of significance ($p < .05$). The calculated partial effect sizes very in between $f^2 = 0.06$ and $f^2 = 0.17$ and are as such smaller than the ones which can be detected with the current sample size (see Section 10). As for some of the calculated analyses, the amount of variance accounted for by the two-way interaction effect between the repeated measurements of NG and the intelligence factors is quite small, it might have occurred that the power of the analyses was too small to detect a possibly existing repeated measurement effect. This is why, a single repeated measurement analysis has been performed without including the independent variables and its results are given in Table 29.

Table 29

Results of the Single Repeated Measurement Analysis Performed to Test the Repeated Measurement Effect of NG

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
Within Subject Variance								
NG	3	21	4.07	.02*	.03*	.02*	0.37	0.28
Polynominal Test of Order 1								

NG	1	7	10.65	.01**	-	-	0.60	0.55
Polynominal Test of Order 2								
NG	1	7	0.02	.88	-	-	0.00	0.00
Polynominal Test of Order 3								
NG	1	7	0.35	.57	-	-	0.05	0.00

Note. * $p < .05$. ** $p < .01$.

CV1 and CV2 were included in this analysis. The result of the repeated measurement effect of NG is significant with $F(3, 21) = 4.07$ ($p < .05$). The partial effect is with $f^2 = 0.37$ large according to Cohen's classification (1988, 1992). As the polynominal test of linear order is significant with $F(1, 7) = 10.65$ ($p < .01$), a linear effect is at hand, which is displayed in Figure 20. NG decreases with the number of practice trials performed.

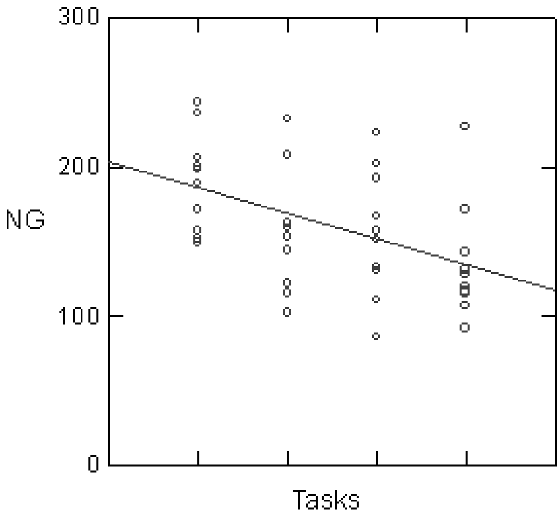


Figure 20. Scatterplot with a linear smoother showing the change of NG overall four practice trials.

Inferential analyses testing the, in H^I_2 expected effects

To test the influence of the repeated measurements on DG and the effect of the intelligence factors on the change of DG (as proposed by H^I_2), general linear model analyses have been performed with DG-T1, DG-T2, DG-T3, and DG-T4 as dependent variables, CV1 and CV2 as control variables, and the intelligence factors as independent variables. Parallel to the procedure chosen to test H^I_1, separate analyses have been performed with the intelligence factors due to the small sample size. The results of the six conducted analyses are printed in Table 30.

Table 30

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DG and its Interaction With the Intelligence Factors as Expected in H^I_2

Source	df_s	df_e	*F*	*p*	G-G	H-F	f^2	ε^2
				Within Subject Variance				
DG	3	18	4.81	.01**	.02*	.01**	0.45	0.35
DGxK	3	18	4.86	.01**	.02*	.01**	0.45	0.36
DG	3	18	0.09	.97	.91	.97	0.02	0.00
DGxB	3	18	0.12	.95	.87	.96	0.02	0.00
DG	3	18	0.64	.60	.53	.60	0.10	0.00
DGxM	3	18	0.67	.58	.52	.58	0.10	0.00
DG	3	18	0.90	.46	.43	.46	0.13	0.00
DGxV	3	18	0.94	.44	.42	.44	0.14	0.00
DG	3	18	0.69	.57	.52	.54	0.10	0.00
DGxN	3	18	0.74	.54	.50	.54	0.11	0.00
DG	3	18	1.09	.38	.36	.38	0.15	0.01
DGxF	3	18	1.11	.37	.36	.37	0.16	0.02
				Polynominal Test of Order 1				
DG	1	6	2.94	.14	-	-	0.33	0.22
DGxK	1	6	3.10	.13	-	-	0.34	0.23
				Polynominal Test of Order 2				
DG	1	6	8.24	.03*	-	-	0.56	0.51
DGxK	1	6	8.20	.03*	-	-	0.58	0.53
				Polynominal Test of Order 3				
DG	1	6	0.01	.93	-	-	0.00	0.00

DGxK	1	6	0.04	.84	-	-	0.01	0.00

Note. $^{*}p < .05$. $^{**}p < .01$.

The results presented in Table 30 yield a significant repeated measurement effect of DG (F (3, 18) = 4.81, p < .01) interacting with K. This two-way interaction effect is significant with F (3, 18) = 4.86 (p < .01) and is large (f^2 = 0.45) according to Cohen's (1988, 1992) classification, as is the repeated measurement effect of DG (f^2 = 0.45). Both effects are, according to the applied polynominal tests of quadratic shape (F (1, 6) = 8.24, p < .05 and F (1, 6) = 8.20, p < .05 respectively). Figure 21 displays both significant effects.

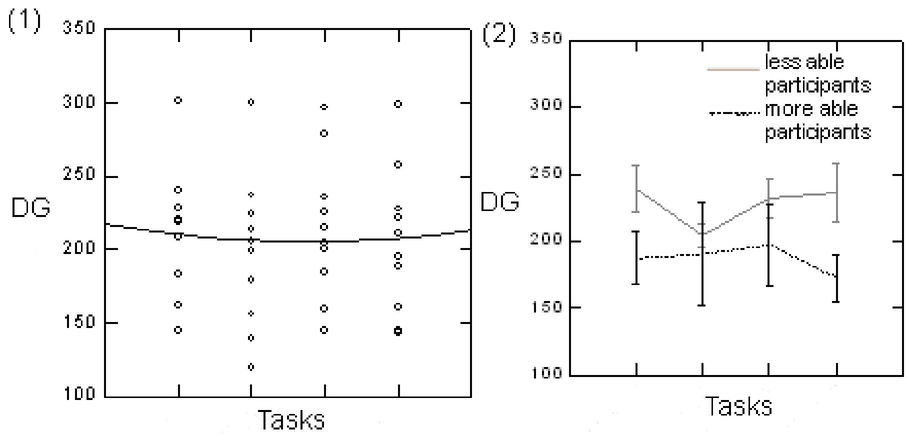


Figure 21. (1) Scatterplot with a quadratic smoother showing the change of DG overall four practice trials. (2) Line plot with standard error bars showing the change of DG overall four practice trials for the participants with lower (dotted line) and greater (drawn-through) K abilities.

As the scatterplot given in Figure 21 shows, DG tends to decrease with the number of practice trials performed, but shows a slight increase between the third and fourth practice trial (see also Table 26). This patter, however, originates because of the different slopes of the graphs for the more and less able participants regarding K, which is depicted by the line plot in Figure 21. While DG decreases for the participants with greater K values with the number of practice trials performed, it slightly resembles a "u"-shaped course for the participants with less K values overall practice trials. Besides the different slopes for the two groups, also their intercepts vary: The participants with greater K abilities require a smaller average duration of the gazes.

<u>Inferential analyses testing the, in H^I_3 expected effects</u>

In H^I_3 a repeated measurement effect of NRG and an interaction with the intelligence factors is expected (see Section 9). To test both effects, general linear model analyses were calculated with NRG-T1, NRG-T2, NRG-T3, and NRG-T4 as dependent variables, CV1 as control variable, and the intelligence factors as independent variables – the latter included in separate general linear model analyses. CV2 was excluded, as it did not account for a significant part of the dependent variables' variance. The results of all six general linear model analyses are given in Table 31.

Table 31

Results of the Repeated Measurement Analyses Performed to Test the Repeated Measurement Effect of NRG and its Interaction With the Intelligence Factors as Expected in H^I_3

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
Within Subject Variance								
NRG	3	21	3.53	.03*	.08	.05*	0.34	0.25
NRGxK	3	21	1.55	.23	.25	.25	0.18	0.08
NRG	3	21	10.34	.00**	.01*	.00**	0.60	0.55
NRGxB	3	21	1.21	.33	.32	.33	0.15	0.05
NRG	3	21	5.55	.01**	.03*	.02*	0.44	0.35
NRGxM	3	21	0.72	.55	.46	.51	0.09	0.00
NRG	3	21	7.05	.00**	.02*	.01*	0.50	0.44
NRGxV	3	21	1.34	.29	.29	.29	0.16	0.07
NRG	3	21	4.65	.01*	.05*	.02*	0.40	0.30
NRGxN	3	21	1.06	.39	.36	.38	0.13	0.00
NRG	3	21	4.95	.01*	.04*	.02*	0.41	0.35
NRGxF	3	21	1.13	.36	.34	.35	0.14	0.00

Polynominal Test of Order 1								
NRG	1	7	0.30	.60	-	-	0.04	0.00
NRGxK	1	7	1.40	.28	-	-	0.17	0.05
NRG	1	7	0.00	.98	-	-	0.00	0.00
NRGxB	1	7	1.51	.26	-	-	0.18	0.07
NRG	1	7	0.00	.98	-	-	0.00	0.00
NRGxM	1	7	0.65	.45	-	-	0.09	0.00
NRG	1	7	0.06	.82	-	-	0.01	0.00
NRGxV	1	7	1.41	.28	-	-	0.17	0.05
NRG	1	7	0.10	.77	-	-	0.01	0.00
NRGxN	1	7	1.31	.29	-	-	0.16	0.05
NRG	1	7	0.07	.80	-	-	0.01	0.00
NRGxF	1	7	1.14	.32	-	-	0.14	0.02
Polynominal Test of Order 2								
NRG	1	7	0.94	.36	-	-	0.12	0.00
NRGxK	1	7	1.54	.26	-	-	0.18	0.10
NRG	1	7	14.35	.01*	-	-	0.67	0.48
NRGxB	1	7	0.01	.94	-	-	0.00	0.00
NRG	1	7	0.12	.04*	-	-	0.47	0.41
NRGxM	1	7	0.08	.79	-	-	0.01	0.00
NRG	1	7	7.09	.03*	-	-	0.50	0.47
NRGxV	1	7	0.08	.78	-	-	0.01	0.00
NRG	1	7	4.98	.06	-	-	0.42	0.38
NRGxN	1	7	0.18	.68	-	-	0.03	0.00
NRG	1	7	3.93	.09	-	-	0.36	0.29
NRGxF	1	7	0.44	.53	-	-	0.06	0.00
Polynominal Test of Order 3								
NRG	1	7	31.15	.00**	-	-	0.82	0.78
NRGxK	1	7	2.63	.15	-	-	0.27	0.14
NRG	1	7	68.34	.00**	-	-	0.91	0.89

NRGxB	1	7	1.33	.29	-	-	0.16	0.00
NRG	1	7	48.27	.00**	-	-	0.87	0.85
NRGxM	1	7	2.47	.16	-	-	0.26	0.14
NRG	1	7	62.08	.00**	-	-	0.89	0.87
NRGxV	1	7	3.41	.11	-	-	0.33	0.14
NRG	1	7	31.60	.00**	-	-	0.82	0.79
NRGxN	1	7	0.86	.39	-	-	0.11	0.00
NRG	1	7	42.11	.00**	-	-	0.86	0.84
NRGxF	1	7	2.27	.18	-	-	0.25	0.14

Note. * $p < .05$. ** $p < .01$.

The results given in Table 31 indicate that for all analyses, the effect of the repeated measurements of NRG is significant ($p = .00 \leq p \leq p = .03$). The partial effect sizes vary due to the different variables included in each analysis between $f^2 = 0.34$ and $f^2 = 0.60$ and are all classified "large" according to Cohen (1988, 1992). As the polynominal tests show, the effects are cubic ($p < .01$) and depicted in Figure 22.

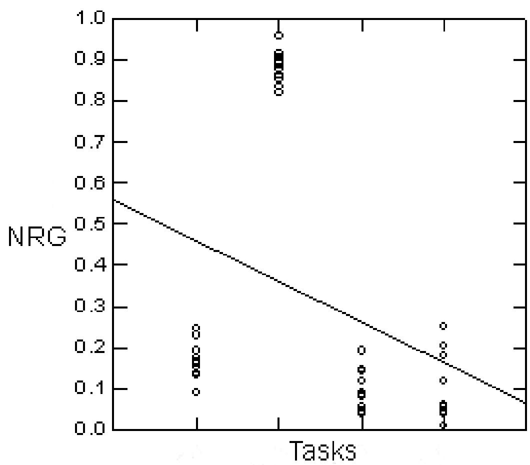


Figure 22. Scatterplot with a linear smoother showing the change of NRG overall four practice trials.

Figure 22 reveals that the second trial shows a totally different range of NRG values as do the first, third and fourth trial (see also Table 26). While all values of the first, third and fourth trial are smaller than NRG = 0.3, the values of the second trial are in between NRG = 0.8 < NRG < NRG = 1.0. Although the other variables do not show peculiarities with the second practice trials and a calculation error was excluded, caution should be taken when interpreting this significant effect.

Inferential analyses testing the, in H^I_4 expected effects

A repeated measurement effect of DRG and a two-way interaction effect of DRG and the intelligence factors are expected in H^I_4. To test these effects, general linear model analyses have been applied with DRG-T1, DRG-T2, DRG-T3 and DRG-T4 as dependent variables and CV1 and CV2 as control variables. The intelligence factors were included as independent variables, one in each conducted analysis. Hence, a total of six analyses have been performed, which results are given in Table 32.

Table 32

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DRG and its Interaction With the Intelligence Factors as Expected in H^I_4

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
			Within Subject Variance					
DRG	3	18	0.34	.80	.68	.80	0.05	0.00
DRGxK	3	18	0.39	.76	.65	.76	0.06	0.00
DRG	3	18	1.32	.30	.30	.30	0.18	0.04
DRGxB	3	18	1.57	.23	.25	.23	0.21	0.08
DRG	3	18	4.11	.02*	.07	.03*	0.41	0.31
DRGxM	3	18	4.54	.02*	.06	.03*	0.43	0.34
DRG	3	18	0.57	.64	.55	.64	0.09	0.00
DRGxV	3	18	0.72	.55	.48	.55	0.11	0.00
DRG	3	18	3.98	.02*	.05*	.02*	0.40	0.30
DRGxN	3	18	4.26	.02*	.04*	.02*	0.42	0.32
DRG	3	18	2.34	.11	.17	.13	0.28	0.16
DRGxF	3	18	2.57	.09	.15	.11	0.30	0.18
			Polynominal Test of Order 1					

DRG	1	6	3.59	.11	-	-	0.38	0.27
DRGxM	1	6	3.83	.10	-	-	0.39	0.29
DRG	1	6	6.12	.05*	-	-	0.51	0.42
DRGxN	1	6	6.46	.04*	-	-	0.52	0.44
Polynominal Test of Order 2								
DRG	1	6	5.91	.05*	-	-	0.50	0.41
DRGxM	1	6	7.45	.03*	-	-	0.55	0.48
DRG	1	6	0.66	.45	-	-	0.10	0.00
DRGxN	1	6	1.04	.35	-	-	0.15	0.01
Polynominal Test of Order 3								
DRG	1	6	4.05	.09	-	-	0.40	0.30
DRGxM	1	6	3.13	.12	-	-	0.35	0.23
DRG	1	6	5.71	.05	-	-	0.49	0.39
DRGxN	1	6	4.68	.07	-	-	0.44	0.34

Note. * $p < .05$.

The results of two analyses (as given in Table 32) reveal significant effects:

- The repeated measurement effect of DRG of the third analysis is significant with F (3, 18) = 4.11 ($p < .05$), which also interacts significantly with M with F (3, 18) = 4.54 ($p < .05$). The significant polynominal tests of the second order (F 1, 6) = 5.91, $p < .05$ and F (1, 6) = 7.45, $p < .05$) further indicate that both effects are of quadratic shape.
- The repeated measurement effect of DRG of the fifth analysis is significant with F (3, 18) = 3.98 ($p < .05$) as well, which also interacts significantly with N (F (3, 18) = 4.26, $p < .05$). Compared, however, to the previously introduced results, the effects are shaped linearly (F (1, 6) = 6.12, $p < .05$ and F (1, 6) = 6.46, $p < .04$ respectively), as yielded by the polynominal test of linear order.

The sizes of the partial effects vary between $f^2 = 0.40$ and $f^2 = 0.43$ and are, thus, large (Cohen, 1988, 1992). Both two-way interaction effects and the repeated measurement effect of DRG are visualized in Figure 23.

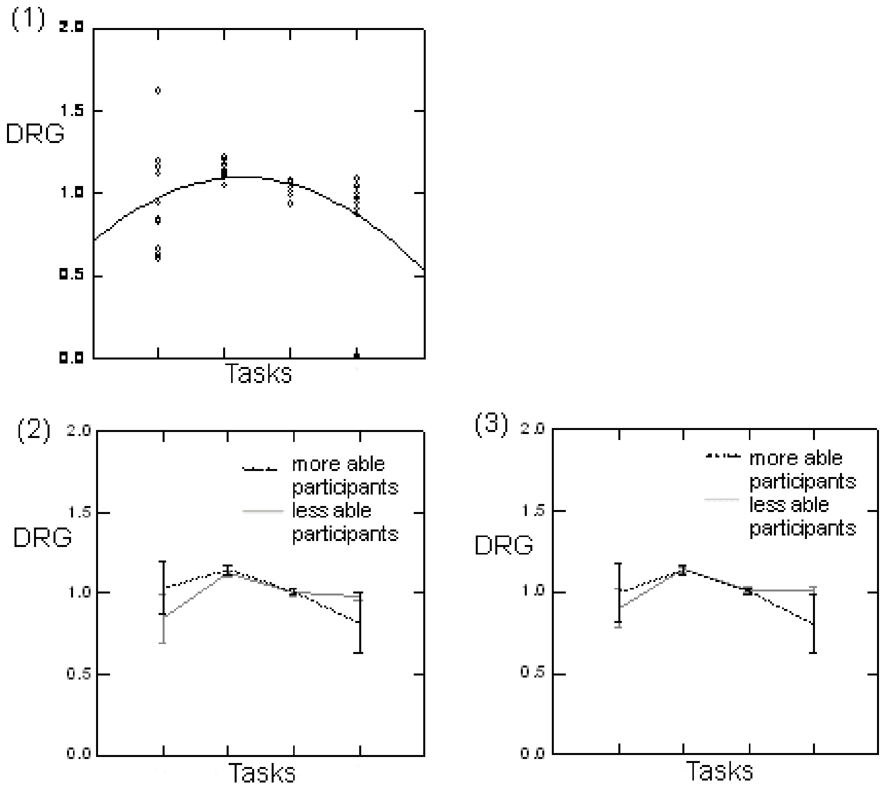


Figure 23. (1) Scatterplot with a quadratic smoother showing the change of DRG overall four practice trials. (2) Line plot with standard error bars showing the change of DRG overall four practice trials for the participants with greater (dotted line) and lower (drawn-through line) M abilities. (3) Line plot with standard error bars showing the change overall four practice trials of DRG for the participants with greater (dotted line) and lower (drawn-through line) N abilities.

The scatterplot given in Figure 23 demonstrates that, after a short initial increase, DRG decreases. Both line plots specify especially this decrease: The slope is steeper for the participants with greater M and N abilities, while the intercept for both artificially, on the mean, dichotomized groups of participants is initially at about the same level. Hence, at the end of the practice trials performed, DRG is smaller for those participants with greater ability levels of M and N.

Inferential analyses testing the, in H^I_5 expected effects

A repeated measurement effect is also expected regarding NPL (see H^I_5, Section 9), as is a two-way interaction of this repeated measurement effect with the intelligence factors. For testing both effects, general linear model analyses have been conducted with NPL-T1, NPL-T2, NPL-T3, and NPL-T4 as dependent variables, CV1 and CV2 as control variables as well as one intelligent factor for each analysis as an independent variable. The results of all six analyses are given in Table 33.

Table 33

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NPL and its Interaction With the Intelligence Factors as Expected in H^{I}_{5}

Source	df_s	df_e	*F*	*p*	G-G	H-F	f^2	ε^2
Within Subject Variance								
NPL	3	18	0.10	.96	.91	.96	0.02	0.00
NPLxK	3	18	0.12	.95	.90	.95	0.02	0.00
NPL	3	18	0.57	.64	.58	.64	0.09	0.00
NPLxB	3	18	0.43	.73	.67	.73	0.07	0.00
NPL	3	18	1.02	.41	.39	.41	0.15	0.01
NPLxM	3	18	0.98	.43	.41	.43	0.14	0.00
NPL	3	18	0.31	.82	.74	.82	0.05	0.00
NPLxV	3	18	0.22	.88	.81	.88	0.04	0.00
NPL	3	18	0.34	.80	.72	.80	0.05	0.00
NPLxN	3	18	0.31	.82	.74	.82	0.05	0.00
NPL	3	18	0.80	.51	.48	.51	0.12	0.00
NPLxF	3	18	0.79	.52	.48	.52	0.12	0.00

The results given in Table 33 do not show significant effects, which could have been caused because of the low power of the study. To increase the probability of detecting a possibly existing repeated measurement effect, df_e has been increased by excluding the independent variables. The result of this single repeated measurement analysis is introduced in Table 34. Such a procedure is justified, as the two-way interaction effects between any of the included independent variable and the repeated measurement effects did not account for a significant part of the dependent variables' variance.

Table 34

Results of the Single General Linear Model Analysis Performed to Test the Repeated Measurement Effect of NPL

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				
NPL	3	21	3.15	.05*	.07	.05*	0.31	0.21
				Polynominal Test of Order 1				
NPL	1	7	5.22	.06	-	-	0.43	0.35
				Polynominal Test of Order 2				
NPL	1	7	3.08	.12	-	-	0.31	0.21
				Polynominal Test of Order 3				
NPL	1	7	0.89	.38	-	-	0.11	0.00

Note. * $p < .05$.

The results given in Table 34 yield a marginally significant repeated measurement effect with F (3, 21) = 3.15 ($p < .05$). The partial effect is - with f^2 = 0.31 – large according to Cohen's (1988, 1992) classification.

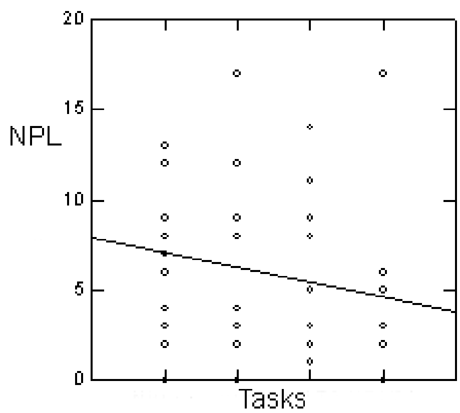


Figure 24. Scatterplot with a linear smoother showing the change of NPL overall four practice trials.

The scatterplot given in Figure 24 confirms the results of the polynominal test (see also Table 26): NPL decreases linearly with the number of practice trials performed.

Inferential analyses testing the, in H^{I}_{6} expected effects

To test whether an effect of the repeated measurements of DPL and an interaction of it with the intelligence factors exist (as proposed in H^{I}_{6}, see Section 9), general linear model analyses have been performed with DPL-T1, DPL-T2, DPL-T3, and DPL-T4 as dependent variables, CV1 and CV2 as control variables and the intelligence factors as independent variables. The independent variables have been included separately, one in each of the analyses performed. The analyses' results are given in Table 35.

Table 35

Results of the Repeated Measurement Analyses Performed to Test the Repeated Measurement Effect of DPL and its Interaction With the Intelligence Factors as Expected in H^{I}_{6}

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				
DPL	3	18	0.53	.67	.61	.67	0.08	0.00
DPLxK	3	18	0.58	.64	.58	.64	0.09	0.00
DPL	3	18	0.30	.83	.75	.83	0.05	0.00
DPLxB	3	18	0.37	.78	.70	.78	0.03	0.00
DPL	3	18	0.42	.75	.65	.75	0.07	0.00
DPLxM	3	18	0.35	.79	.69	.79	0.06	0.00
DPL	3	18	0.39	.63	.58	.63	0.09	0.00
DPLxV	3	18	0.71	.56	.52	.56	0.11	0.00
DPL	3	18	0.37	.77	.68	.76	0.06	0.00
DPLxN	3	18	0.35	.78	.70	.79	0.06	0.00
DPL	3	18	0.28	.83	.74	.84	0.05	0.00
DPLxF	3	18	0.26	.85	.76	.85	0.04	0.00

As the results given in Table 35 reveal, neither the repeated measurement effect of DPL is significant, nor is its interaction with any of the intelligence factors. The two-way interaction effects do hardly account for variance of the dependent variables. Hence, the inclusion of the independent variables in the analyses might have reduced df_e without accounting for much variance. Hence, the intelligence factors were excluded as independent variables and a single repeated measurement analysis was performed only with DPL-T1, DPL-T2, DPL-T3, and DPL-T4 as dependent and CV1 and CV2 as control variables. The results are printed in Table 36.

Table 36

Results of the Single General Linear Model Analysis Performed to Test the Repeated Measurement Effect of DPL

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
Within Subject Variance								
DPL	3	21	0.85	.48	.45	.48	0.11	0.00

However, the results of the single general linear model analysis (given in Table 36) also do not reach the level of significance (F (3, 21) = 0.85, p > .05).

<u>Inferential analyses testing the, in H^I_7 expected effects</u>

General linear model analyses have been performed to test the effect of the repeated measurements on DAG and its interaction with the intelligence factors (as proposed in H^I_7). DAG-T1, DAG-T2, DAG-T3, and DAG-T4 were included in the analyses as dependent variables and one of the intelligence factors as independent variable in each analysis, so that a total of six analyses were performed, which results are given in Table 37. CV1 and CV2 were excluded as control variables as they only accounted for a small amount of the variance of the dependent variables.

Table 37

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DAG and its Interaction With the Intelligence Factors as Expected in H^I_7

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				
DAG	3	24	2.23	.11	.15	.12	0.22	0.12
DAGxK	3	24	2.01	.14	.17	.15	0.20	0.10
DAG	3	24	2.42	.09	.13	.10	0.23	0.14
DAGxB	3	24	2.06	.13	.16	.14	0.21	0.11
DAG	3	24	0.63	.61	.56	.61	0.07	0.00
DAGxM	3	24	0.52	.68	.62	.68	0.03	0.00
DAG	3	24	2.07	.13	.17	.14	0.21	0.11
DAGxV	3	24	1.80	.17	.20	.18	0.18	0.08
DAG	3	24	1.06	.39	.37	.39	0.12	0.01
DAGxN	3	24	0.91	.45	.42	.45	0.10	0.00
DAG	3	24	3.86	.02*	.04*	.02*	0.33	0.24
DAGxF	3	24	3.57	.03*	.05*	.03*	0.31	0.22
				Polynominal Test of Order 1				
DAG	1	8	0.00	.96	-	-	0.00	0.00
DAGxF	1	8	0.02	.89	-	-	0.00	0.00
				Polynominal Test of Order 2				
DAG	1	8	12.34	.01**	-	-	0.61	0.56
DAGxF	1	8	11.30	.01**	-	-	0.59	0.53
				Polynominal Test of Order 3				
DAG	1	8	2.38	0.16	-	-	0.23	0.13
DAGxF	1	8	2.39	0.16	-	-	0.23	0.13

Note. * $p < .05$. ** $p < .01$.

The general linear model analyses testing the repeated measurement effect of DAG and its interaction with F yield two significant results (see Table 37):

- First, the repeated measurement effect is significant with $F\ (3, 24) = 3.86$ ($p < .05$). The partial effect is – according to the results of the polynominal tests –

quadratic (F (1, 8) = 12.34, $p < .01$) and is, based on Cohen's (1988, 1992) classification large ($f^2 = 0.33$).

- Second, the DAG's repeated measurement effect significantly interacts with F (F (3, 24) = 3.57, $p < .05$). This interaction is also quadratic according to the polynonominal tests (F (1, 8) = 11.30, $p < .01$) and the partial effect is judged in between large and medium-sized ($f^2 = 0.31$) based on Cohen's (1988, 1992) classification.

The quadratic shape of the repeated measurement effect of DAG is demonstrated in Figure 25, as is its interaction with F.

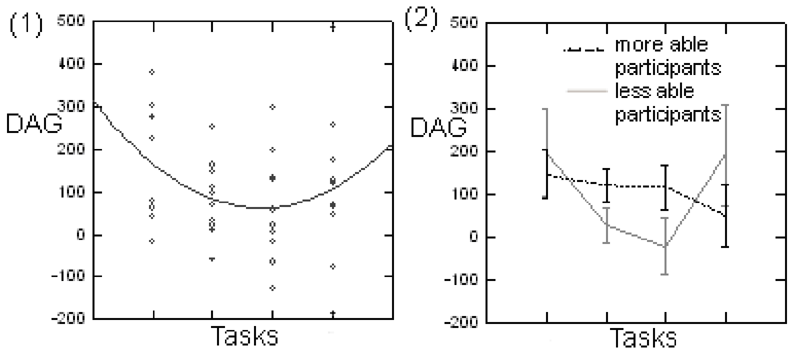


Figure 25. (1) Scatterplot with a quadratic smoother showing the change of DAG overall four practice trials. (2) Line plot with standard error bars showing the change of DAG overall four practice trials for the participants with greater (dotted line) and lower (drawn-through line) F abilities.

As Figure 25 demonstrates, for the participants with greater F, DAG shows a general decline, while the change of DAG for participants with smaller F follows a "u"-shaped form, so that at the end of the practice trials, the participants with greater abilities reach a smaller DAG than do the participants with smaller abilities.

Inferential analyses testing the, in H^I_8 expected effects

H^I_8 proposes a repeated measurement effect of NIG and an interaction of it with the participants' psychomotor abilities. In order to test the existence of these effects, general linear model analyses have been performed with NIG-T1, NIG-T2, NIG-T3, and NIG-T4 as dependent variables, CV2 as a control variable and one of the psychomotor factors as independent variables in each analysis. CV1 was excluded as it did not account for a significant part of the dependent variables' variance. The results of the four analyses are given in Table 38.

Table 38

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NIG and its Interaction With the Psychomotor Abilities as Expected in H^{I}_{8}

Source	df_s	df_e	*F*	*p*	G-G	H-F	f^2	ε^2
				Within Subject Variance				
NIG	3	21	0.28	.84	.76	.84	0.04	0.00
NIGxST	3	21	0.51	.68	.61	.68	0.07	0.00
NIG	3	21	1.18	.34	.34	.34	0.15	0.06
NIGxPR	3	21	3.18	.05*	.07	.05*	0.31	0.23
NIG	3	21	1.24	.32	.32	.32	0.15	0.03
NIGxVE	3	21	4.06	.02*	.04*	.02*	0.37	0.28
NIG	3	21	2.26	.85	.80	.85	0.04	0.00
NIGxTP	3	21	1.73	.19	.21	.19	0.20	0.13
				Polynominal Test of Order 1				
NIG	1	7	1.96	.21	-	-	0.22	0.15
NIGxPR	1	7	6.89	.03*	-	-	0.50	0.45
NIG	1	7	3.05	.12	-	-	0.30	0.20
NIGxVE	1	7	11.78	.01**	-	-	0.63	0.58
				Polynominal Test of Order 2				
NIG	1	7	0.06	.81	-	-	0.01	0.00
NIGxPR	1	7	0.21	.66	-	-	0.03	0.00
NIG	1	7	1.06	.34	-	-	0.13	0.00
NIGxVE	1	7	1.76	.23	-	-	0.20	0.00
				Polynominal Test of Order 3				
NIG	1	7	1.03	.34	-	-	0.13	0.00
NIGxPR	1	7	1.40	.28	-	-	0.17	0.00

NIG	1	7	0.30	.60	-	-	0.04	0.00
NIGxVE	1	7	0.52	.49	-	-	0.07	0.00

Note. * $p < .05$. ** $p < .01$.

As the results in Table 38 indicate, significant are the two-way interactions between the repeated measurement effect of NIG and VE (F (3, 21) = 3.18, $p < .05$) as well as the one with PR (F (3, 21) = 4.06, $p < .05$). Both effects are linear according to the results of the performed polynominal tests (F (1, 7) = 6.89, $p < .05$ and F (1, 7) = 11.78, $p < .01$) and classified as large ($f^2 = 0.31$ and $f^2 = 0.37$ respectively) based on Cohen's (1988, 1992) classification. A visualization of both interaction effects is given in Figure 26.

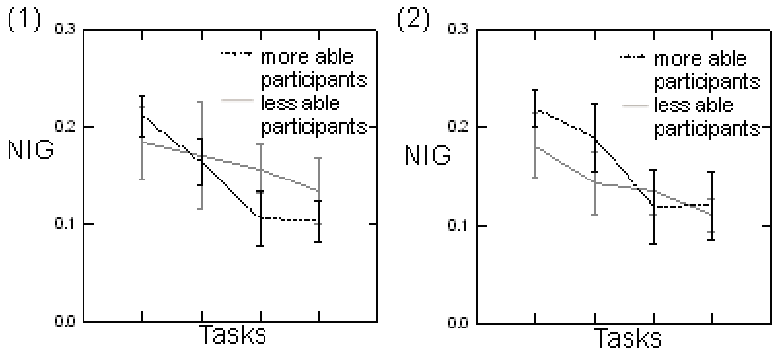


Figure 26. (1) Line plot with standard error bars showing the change of NIG overall four practice trials for the participants with greater (dotted line) and lower (drawn-through line) VE values. (2) Line plot with standard error bars showing the change of NIG overall four practice trials for the participants with greater (dotted line) and lower (drawn-through line) PR values.

Both line plots given in Figure 26 depict a similar shape: While there is hardly a difference for the intercept regarding the artificially dichotomized groups of participants, the participants with greater VE and PR values show a steeper slope. Between the third and fourth practice trial there is hardly an improvement for the participants with greater psychomotor abilities, but the less able participants still show a decline in their NIG, so that it can be argued that the participants with the greater ability level have already reached the final level of NIG.

<u>Inferential analyses testing the, in H^I_9 expected effects</u>

An effect of the repeated measurements of DIG and an interaction of it with the psychomotor abilities is expected in H^I_9. In order to test the existence of these effects, general linear model analyses have been performed with DIG-T1, DIG-T2, DIG-T3, and DIG-T4 as dependent variables, CV1 as control variable and – for each analysis – one psychomotor abilities as an independent variable. The results of the four analyses are introduced in Table 39.

Table 39

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DIG and its Interaction With the Psychomotor Abilities as Expected in H^I_9

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
Within Subject Variance								
DIG	3	21	3.49	.03*	.07	.04*	0.33	0.24
DIGxST	3	21	3.14	.05*	.09	.06	0.31	0.21
DIG	3	21	17.20	.00**	.00**	.00**	0.71	0.67
DIGxPR	3	21	15.63	.00**	.00**	.00**	0.69	0.65
DIG	3	21	3.59	.03*	.07	.03*	0.34	0.24
DIGxVE	3	21	3.04	.05*	.09	.05*	0.30	0.20
DIG	3	21	2.74	.07	.11	.07	0.28	0.18
DIGxTP	3	21	2.25	.11	.15	.11	0.24	0.14
Polynominal Test of Order 1								
DIG	1	7	4.17	.08	-	-	0.37	0.28
DIGxST	1	7	3.16	.01*	-	-	0.67	0.21
DIG	1	7	20.67	.00**	-	-	0.75	0.71
DIGxPR	1	7	17.46	.00**	-	-	0.71	0.67
DIG	1	7	2.33	.17	-	-	0.25	0.14
DIGxVE	1	7	1.46	.27	-	-	0.17	0.05
Polynominal Test of Order 2								

DIG	1	7	0.59	.08	-	-	0.08	0.00
DIGxST	1	7	0.34	.58	-	-	0.05	0.00
DIG	1	7	18.21	$.00^{**}$	-	-	0.72	0.68
DIGxPR	1	7	16.17	$.01^{**}$	-	-	0.70	0.65
DIG	1	7	6.53	$.04^{*}$	-	-	0.48	0.41
DIGxVE	1	7	5.38	$.05^{*}$	-	-	0.44	0.35
Polynominal Test of Order 3								
DIG	1	7	13.87	$.01^{**}$	-	-	0.67	0.62
DIGxST	1	7	16.57	$.01^{**}$	-	-	0.70	0.66
DIG	1	7	9.81	$.02^{*}$	-	-	0.58	0.53
DIGxPR	1	7	11.75	$.01^{*}$	-	-	0.63	0.58
DIG	1	7	3.44	.11	-	-	0.33	0.24
DIGxVE	1	7	4.74	.07	-	-	0.40	0.32

Note. * $p < .05$. ** $p < .01$.

The results point at three analyses with significant results:

- First, the repeated measurement effect of DIG and its interaction with ST are significant with F (3, 21) = 3.49 ($p < .05$) and with F (3, 21) = 3.14 ($p < .05$). Both partial effects are classified as large according to Cohen's (1988, 1992) classification ($f^2 = 0.33$ and $f^2 = 0.31$ respectively). As the three polynominal tests performed indicate, both effects follow a cubic shape (F (1, 7) = 1.87, $p < .01$ and F (1, 7) = 16.57, $p < .01$).
- Second, the repeated measurement effect of DIG is significant as well as its interaction with PR (F (3, 21) = 17.20, $p < .01$ and F (3, 21) = 15.63, $p < .01$). The partial effects are large ($f^2 = 0.71$ and $f^2 = 0.69$) and follow a cubic shape, as indicated by the polynominal tests of cubic order, which are significant with F (1, 7) = 9.81 ($p < .05$) and F (1, 7) = 11.75 ($p < .01$).
- Third, the repeated measurement effect of DIG and its interaction of it with VE is significant with F (3, 21) = 3.59 ($p < .05$) and F (3, 21) = 3.04 ($p < .05$) respectively. Again, both partial effects are large ($f^2 = 0.34$ and $f^2 = 0.30$), but are shaped quadratically (F (1, 7) = 6.53, $p < .05$ and F (1, 7) = 5.38, $p < .05$).

The sizes of the effects of the repeated measurements vary due to the different variables, which have been included in the analyses. The scatterplot given in Figure 27 shows this effect's shape, further depicted are the line plots comparing the artificially dichotomized groups of participants with greater and lower psychomotor abilities and their course of adaptation regarding DIG.

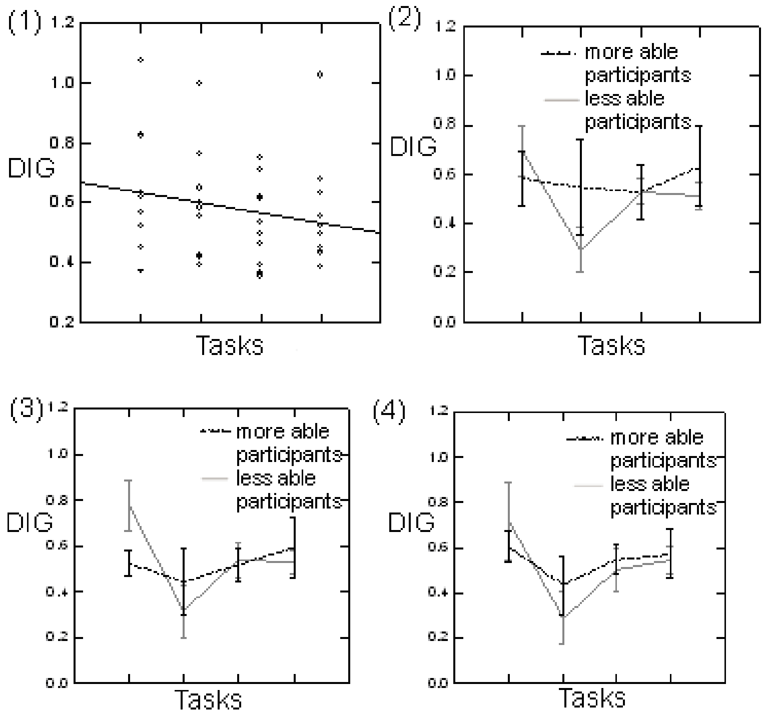


Figure 27. (1) Scatterplot with a linear smoother showing the change of DIG overall four practice trials. (2) Line plot with standard error bars showing the change of DIG overall four practice trials for the participants with greater (dotted line) and lower (drawn-through line) ST abilities. (3) Line plot with standard error bars showing the change of DIG overall four practice trials for the participants with greater (dotted line) and lower (drawn-through line) PR abilities. (4) Line plot with standard error bars showing the different course of the DIG overall practice trials for the participants with greater (dotted line) and lower (drawn-through line) VE abilities.

The scatterplot given in Figure 27 depict that the values of DIG tend to decrease overall practice trials. The three line plots visualizing the different shapes of DIG for the artificially dichotomized groups of participants with greater and lower psychomotor abilities specify that general picture of the scatterplot and display the different shapes of the participants with greater and lower psychomotor abilities. The cubic shapes are especially coined by the participants with less psychomotor abilities, especially regarding ST and PR, while the participants with greater psychomotor abilities show a course, which resembles more a linear course, parallel to the x-axis.

Inferential analyses testing the, in H^I_{10} expected effects

In order to test whether DGO can be predicted by OR at the end but not at the beginning of the adaptation process (H^I_{10}), another statistical approach has been taken compared to the other hypotheses tested: An object has been chosen, which was used overall practice trials and which played a significant role in task achievement, i.e., Pot 1 (for a list of all objects, see Appendix I). For each task a univariate general linear model analysis has been performed with OR as independent and DGO as dependent variable. To control the influence of the duration of an operation, the average duration of a gaze was included as a control variable. The results are summarized in Table 40.

Table 40

Results of the Univariate General Linear Model Analyses Performed to Test the Impact of the Object Relevance on the Gaze Duration as Expected in H^I_{10}

Source	df_s	df_e	F	p	f^2	ε^2
Task 1	1	7	0.70	.43	0.09	0.00
Task 2	1	7	2.52	.16	0.27	0.15
Task 3	1	7	0.48	.51	0.06	0.00
Task 4	1	7	9.29	.02*	0.57	0.50

Note. * $p < .05$.

As Table 40 indicates, OR is a significant predictor for DGO for the last task (F (1, 7) = 9.29, $p < .05$) and not for the first one (F (1, 7 = 0.70, $p = .43$), as stated in the hypotheses. However, the partial effect sizes do not continuously increase: While for the second trial, the partial effect size is $f^2 = 0.27$ ($p = .16$), it only reaches $f^2 = 0.06$ ($p = .51$) for the third practice trial. Hence, a clear relationship of increasing effects between the variables of interest is not given. The partial effect size of the significant analysis is classified as large ($f^2 = 0.57$) according to Cohen (1988, 1992).

Inferential analyses testing the, in H^I_{11} expected effects

The last hypothesis, i.e., H^I_{11}, expects a repeated measurement effect of SDG and an interaction of it with the intelligence factors. In order to test both expected effects, general linear model analyses have been performed with SDG-T1, SDG-T2, SDG-T3, and SDG-T4 as dependent variables, CV1 as a control variable and one of the intelligence factors included in each analysis as an independent variable. Separate analyses have been conducted for the six intelligence factors, so that altogether six general linear model analyses have been performed, which results are printed in Table 41.

Table 41

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of SDG and its Interaction With the Intelligence Factors as Expected in H^I_{11}

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				
SDG	3	21	3.66	.03*	.10	.08	0.34	0.25
SDGxK	3	21	3.42	.04*	.10	.09	0.33	0.23
SDG	3	21	3.06	.05	.12	.10	0.30	0.20
SDGxB	3	21	2.69	.07	.14	.13	0.28	0.17
SDG	3	21	1.74	.19	.23	.22	0.20	0.08
SDGxM	3	21	1.54	.23	.26	.26	0.18	0.06
SDG	3	21	5.23	.01**	.05*	.04*	0.43	0.35
SDGxV	3	21	4.82	.01**	.06	.04*	0.41	0.31
SDG	3	21	1.29	.31	.30	.30	0.16	0.03
SDGxN	3	21	1.13	.36	.33	.34	0.14	0.02
SDG	3	21	2.80	.07	.13	.12	0.29	0.18
SDGxF	3	21	2.56	.08	.15	.14	0.27	0.16
				Polynominal Test of Order 1				
SDG	1	7	3.27	.11	-	-	0.32	0.22

SDGxK	1	7	3.04	.13	-	-	0.30	0.20
SDG	1	7	4.86	.06	-	-	0.41	0.33
SDGxV	1	7	4.44	.07	-	-	0.39	0.30
Polynominal Test of Order 2								
SDG	1	7	3.86	.09	-	-	0.36	0.26
SDGxK	1	7	3.61	.10	-	-	0.34	0.25
SDG	1	7	5.03	.06	-	-	0.42	0.33
SDGxV	1	7	4.62	.07	-	-	0.40	0.31
Polynominal Test of Order 3								
SDG	1	7	6.36	.04*	-	-	0.48	0.40
SDGxK	1	7	6.20	.08	-	-	0.47	0.39
SDG	1	7	11.84	.01**	-	-	0.63	0.58
SDGxV	1	7	11.51	.01**	-	-	0.62	0.57

Note. * $p < .05$. ** $p < .01$.

As the results given in Table 41 indicate, there is a significant repeated measurement effect of SDG in the analyses performed with K and V included as independent variables (F (3, 21 = 3.66, $p < .05$ and F (3, 21) = 5.23, $p < .01$). The numbers vary due to the different variables included in the analyses. The sizes of both partial effects are considered large ($f^2 = 0.34$ and $f^2 = 0.43$), based on Cohen's (1988, 1992) classification. The polynominal tests applied show that the effects follow a cubic shape (F (1, 7) = 6.36, $p < .05$ and F (1, 7) = 11.84, $p < .01$). The two interaction effects between the repeated measurement effect of SDG and K and V respectively are also significant with F (3, 21) = 3.42 ($p < .05$) and F (3, 21) = 4.82 ($p < .01$). While the latter effect, i.e., the one with V is large ($f^2 = 0.41$), the first one is smaller ($f^2 = 0.33$), but still judged as large following Cohen's (1988, 1992) classification. The polynominal tests indicate that the effects follow a cubic shaped (F (1, 7) = 6.20, $p = .08$ and F (1, 7) = 11.51, $p < .01$).

As the scatterplot given in Figure 28 reveals, SDG approaches zero with the number of practice trials performed. However, the scatterplot also shows an extreme value for the first practice trial, which might have caused the significant results. To check the impact of each participant on the stability of the results, special analyses have been executed, which are discussed in Section 15.3.1.4. The line plots also printed in Figure 28 reveal that the participants with greater abilities do not show a change while practicing the four tasks: The line runs nearly parallel with the x-axis. In contrast, the participants with the lower abilities show a cubic curve approaching the line of the participants with the higher able participants. However, as mentioned before, the different shape of SDG for the two artificially dichotomized groups might have been caused by the extreme value detected in the scatterplot. Hence, caution must be taken and the results of Section 15.3.1.4 considered, when interpreting these effects.

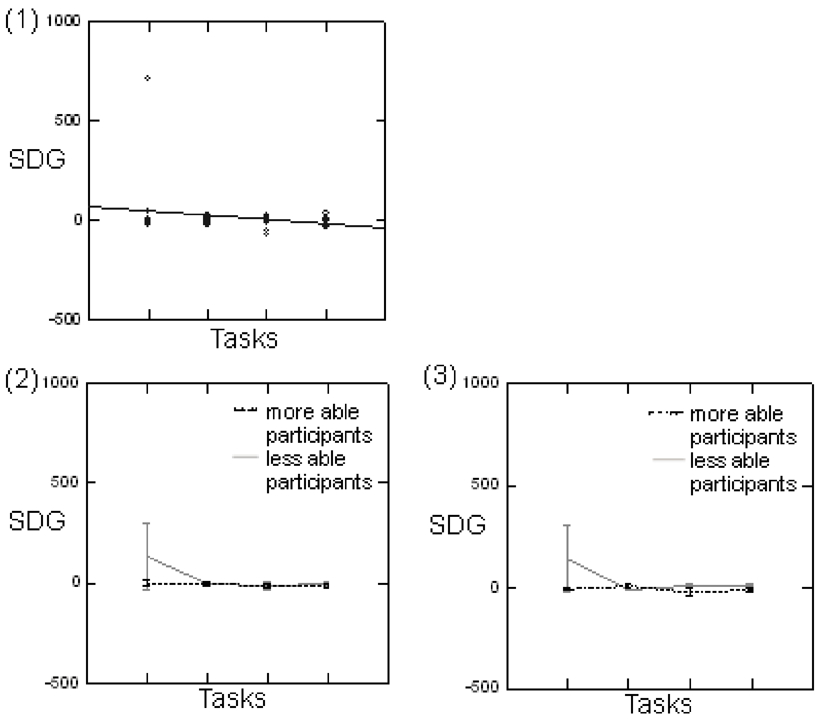


Figure 28. (1) Scatterplot with a linear smoother showing the change of SDG overall four practice trials. (2) Line plot with standard error bars showing the change of SDG overall four practice trials for the participants with greater (dotted line) and lower (drawn-through line) K abilities. (3) Line plot with standard error bars showing the change of SDG for the participants with greater (dotted line) and lower (drawn-through line) V abilities.

15.3.1.3. Test of the assumptions.

The, in Section 15.3.1.2 described results can only be interpreted if the assumptions underlying the applied inferential statistics are met (see also Section 15.1). These assumptions refer to homoscedasticity, the independence of the residuals, and their normal distribution and were checked first by plotting the scatterplots of the residuals for each analysis against each independent variable and the residuals against the ordered values. Irregularities were detected (see also Figure 28); however, as stated by Scheffé (1959) and Cohen and Cohen (1983), the *F*-distribution is robust to small violations of the assumptions.

To complement the graphical tests, the Mauchly-Tests were performed in a second step for each of the conducted analyses with repeated measurements and its results are given in Appendix K. Some of the Mauchly-Tests were significant, so that the in Section 15.3.1.2 introduced *p*-values cannot be applied. Instead, the degrees of freedom must be corrected according to the conservative G-G or the more liberal H-F formulas and their probability values interpreted. The analyses, for which the sphericity assumptions were violated and the correction of these results are discussed in the following:

- The sphericity assumption was violated for the four analyses performed when testing the repeated measurement effect of NRG (H^I_3): As given in Appendix K, the Mauchly-Tests were significant for the analyses, in which K, B, M, and V were included as independent variables ($\chi^2 = 11.88$, $\chi^2 = 12.08$, $\chi^2 = 11.80$ and $\chi^2 = 13.53$ with $df = 5$ and all $p < .05$). Hence, the degrees of freedom were adjusted according to the G-G and H-F formulas and the p-levels re-calculated and reported as G-G and H-F values in Table 31. When interpreting the G-G values, the repeated measurement effects of NRG remain significant ($p < .05$), except that the repeated measurement effect does not reach the significance level when tested with the interaction with K (G-G = .08, see Table 31). The more liberal H-F values are all at least marginally significant (H-F < .05).
- Regarding the general linear model analyses applied to test H^I_4, the Mauchly-Test was significant for two analyses: regarding the analysis testing the repeated measurement effect of DRG and its interaction with M and regarding

the analysis testing the repeated measurement effect of DRG and its interaction with N. The Mauchly-Test testing the sphericity assumption of the first analysis was significant with $\chi^2 = 19.00$ ($df = 5$, $p < .05$), as given in Appendix K. When correcting the degrees of freedom according to the conservative G-G formula, neither the repeated measurement effect of DRG nor its interaction with M do reach the level of significance (G-G = .07 and G-G = .06 respectively, see Table 32). The H-F values still reach the level of significance (H-F <.05 for both effects); however, as the H-F correction formula is more liberal, caution must be taken when interpreting these two results. The Mauchly-Test testing the assumption regarding the second mentioned analysis were significant with $\chi^2 = 14.26$ ($df = 5$, $p < .05$, see Appendix K). After correcting the degrees of freedom, the results are still significant (G-G < .05 and H-F < .05) for both, the repeated measurement effect of DRG and its interaction with M.

- Last, the two analyses, testing the repeated measurement effect of SDG and its interaction with K and testing the effect of the repeated measurements of SDG and its interaction with V (H^{I}_{11}) also yielded significant results of the Mauchly-Tests (see Appendix K): The first test was significant with $\chi^2 = 35.88$ ($df = 5$, $p < .01$), the second one with $\chi^2 = 35.00$ ($df = 5$, $p < .01$). For both analyses the interpretation of the results changes: Neither the repeated measurement effect of SDG nor its interaction with K remain significant when applying the G-G or H-F formulas: The G-G-corrected probability values for both effects only reach a significance level of G-G = .10, while the more liberal H-F values refer to H-F = .08 and H-F = .09 respectively (see Table 41). In the analysis, in which V was included, the repeated measurement effect of SDG remains significant when applying the correction formulas according to G-G (G-G = .05) and H-F (H-F = .04). Its interaction, however, with V is no longer significant when applying the G-G formula to correct the degrees of freedom (G-G = .06); whereas applying the more liberal H-F correction still reaches the significance level of $p < .05$ with H-F = .04.

For all other tests, for which the Mauchly-Test was not significant (see Appendix K), the results of the inferential statistics (given in Section 15.3.1.2) must still be interpreted with caution, as the Mauchly-Test tends not to show violations of the sphericity assumptions for small sample sizes (see e.g., Rasch, Friese, Hofmann, & Naumann, 2006).

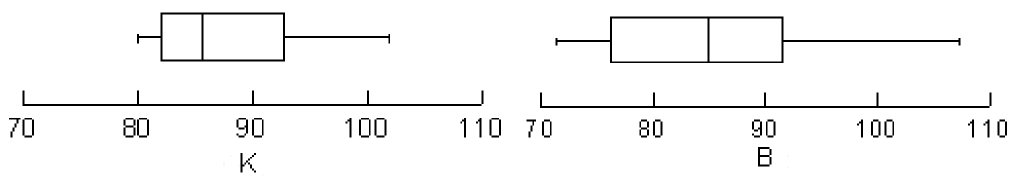
15.3.1.4. Stability of the results.

Especially due to the small sample size, the stability of the results given in Section 15.3.1.2 needs to be examined. Three threats will be discussed: multicollinearity, suppressor effects, and irregularities in the sample.

To analyze, whether multicollinearity might have caused instable results, the correlations given in Appendix J were checked whether any of them is bigger than r = .90, which is when multicollinearity might bias the inferential statistics' results. Only one correlations, i.e., $r_{B,NG\text{-}T2} = .90$ ($p < .01$), reaches that level. Hence, multicollinearity is not expected as causing instable results of the analyses at hand.

The same conclusion is drawn regarding the existence of suppressor effects: These effects result out of the pattern that the independent variables correlate highly, but only one of these correlates to a high degree with the dependent variable. Hence, to examine whether suppressor variables are in the data set, the correlations and especially the ones between the independent variables have been analyzed (given in Appendix J), but none is considered large enough to cause suppressor effects.

To detect irregularities in the sample, two approaches have been taken: First, boxplots of all independent variables (see Figure 29) and of the dependent variables reflecting the human gaze behavior of interest (see Figure 30) are given.



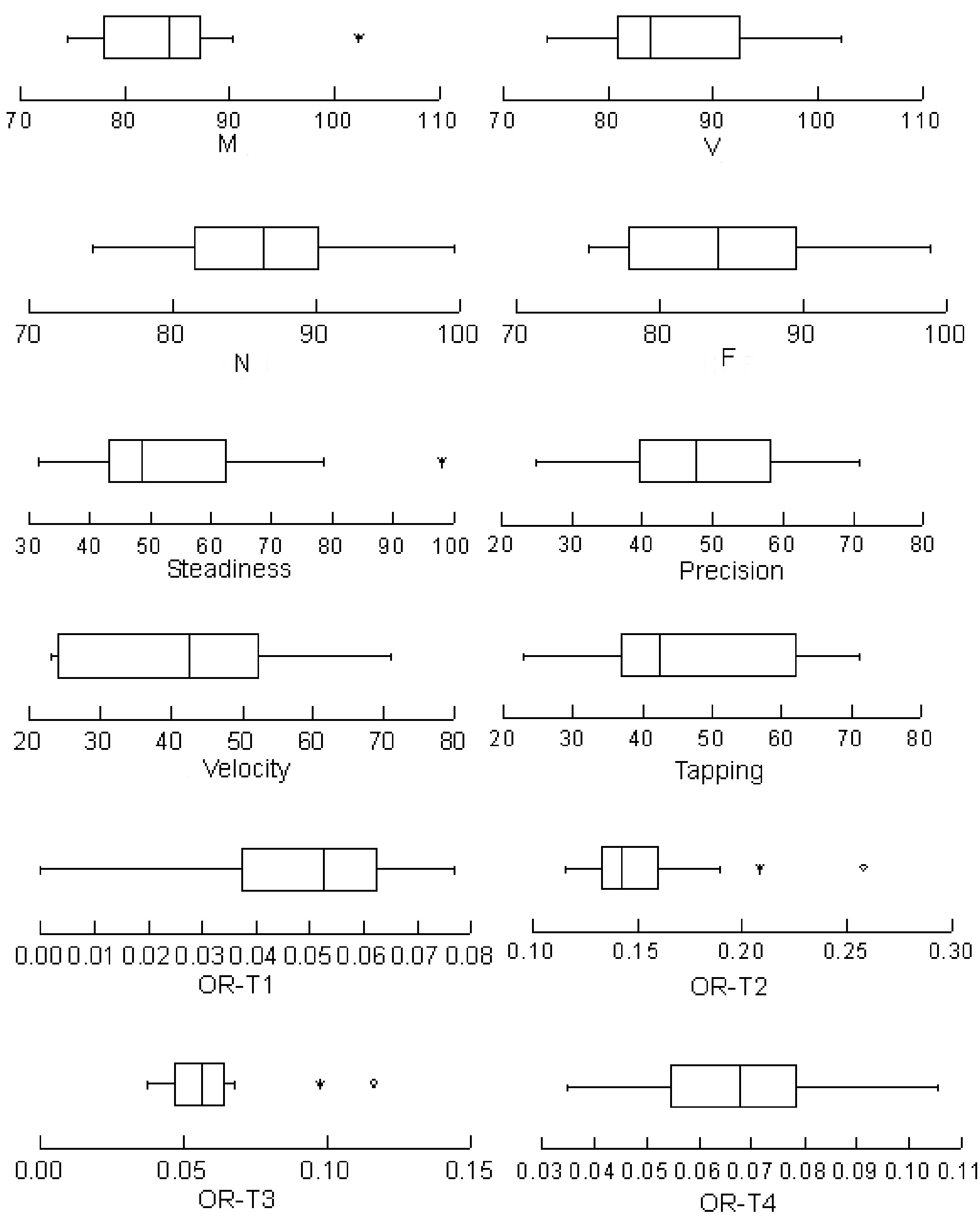
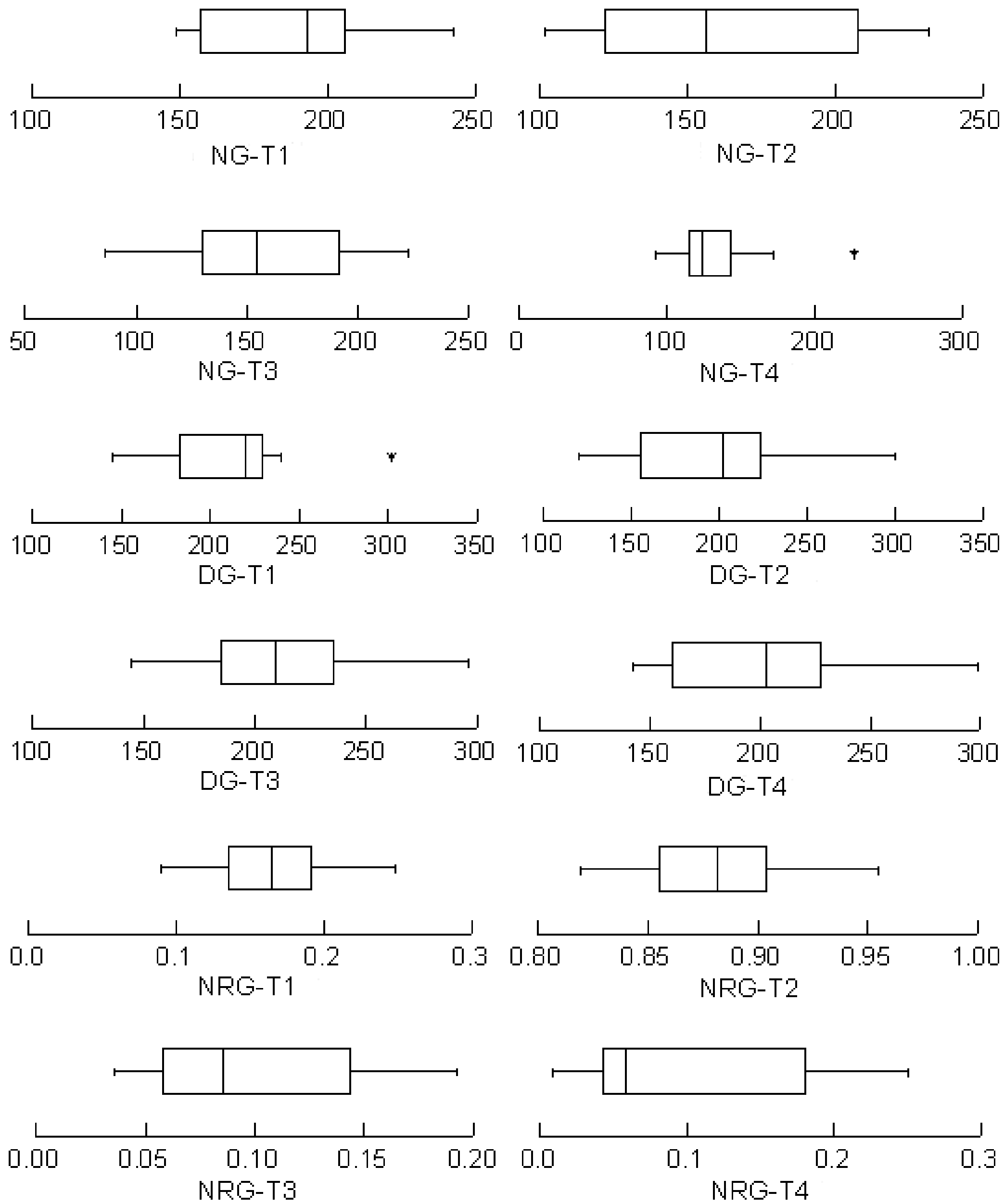
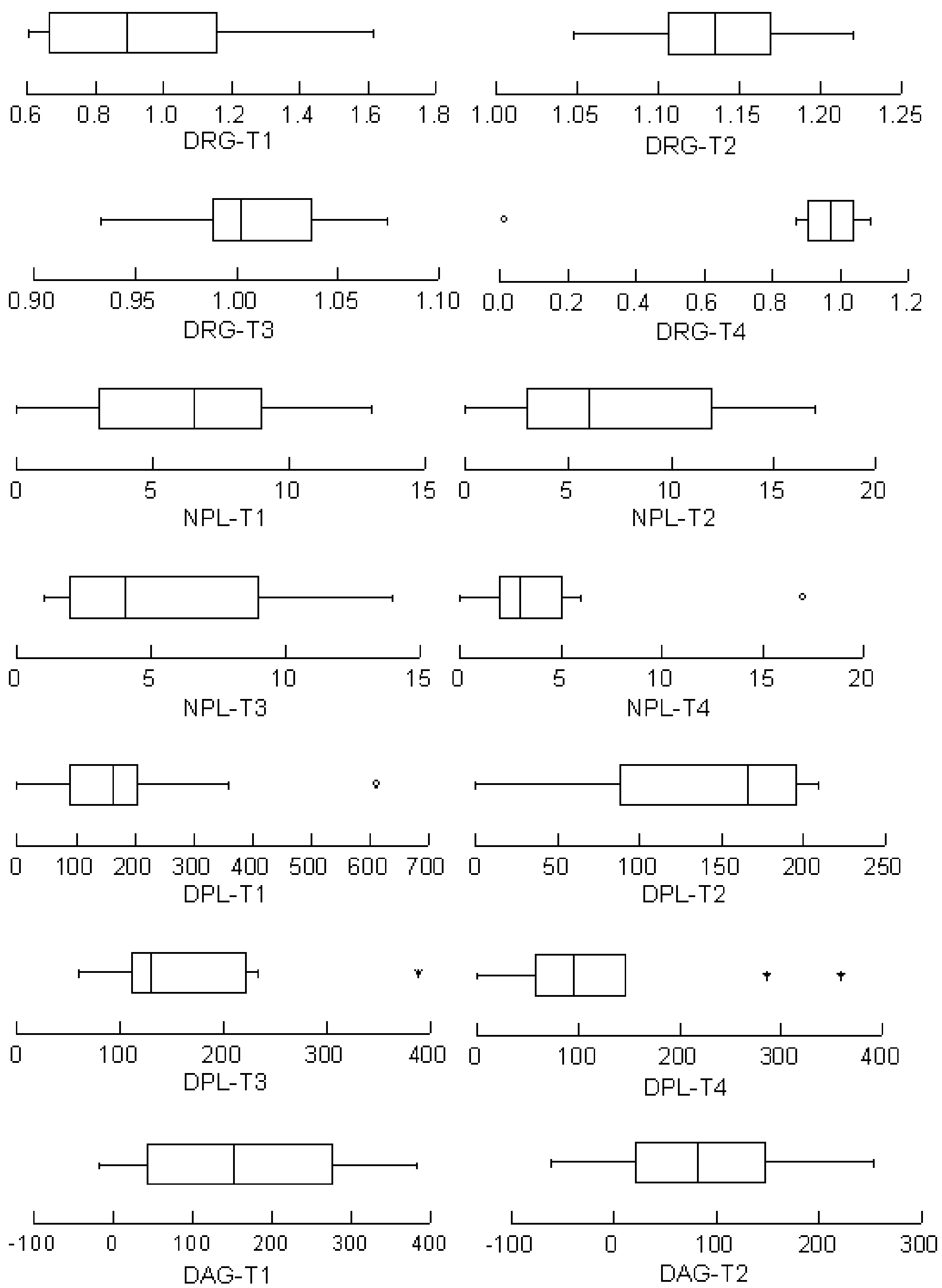
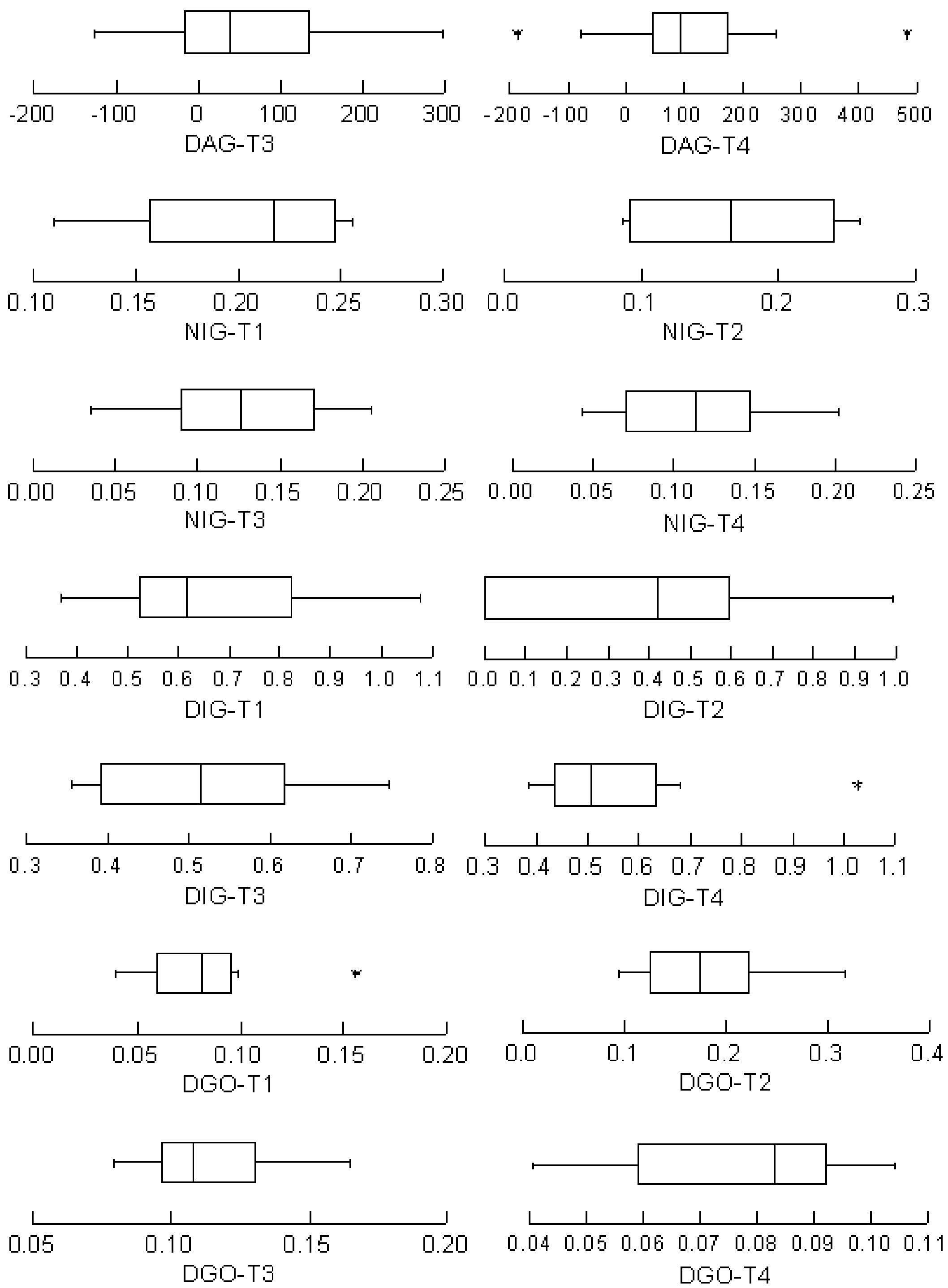


Figure 29. Boxplots of the independent variables.

The boxplots presented in Figure 29 and Figure 30 demonstrate that only two outliers are in the data set regarding OR-T2, OR-T3, DPL-T4, and SDG-T3, three outliers are at hand regarding SDG-T4, but the other dependent and independent variables of interest have either no or only one outlier. SDG-T1 shows the outlier, which has already been detected in the scatterplot given in Figure 28. The outliers detected derive from various participants, so that there is no participant having extreme values on more than one variable. Hence, no participant has been excluded from the inferential analyses.




0.6 0.8 1.0 1.2 1.4 1.6 1.8
DRG-T1
1.00 1.05 1.10 1.15 1.20 1.25
DRG-T2
0.90 0.95 1.00 1.05 1.10
DRG-T3
0.0 0.2 0.4 0.6 0.8 1.0 1.2
DRG-T4
0 5 10 15
NPL-T1
0 5 10 15 20
NPL-T2
0 5 10 15
NPL-T3
0 5 10 15 20
NPL-T4
0 100 200 300 400 500 600 700
DPL-T1
0 50 100 150 200 250
DPL-T2
0 100 200 300 400
DPL-T3
0 100 200 300 400
DPL-T4
-100 0 100 200 300 400
DAG-T1
-100 0 100 200 300
DAG-T2


-200 -100 0 100 200 300
DAG-T3
-200 -100 0 100 200 300 400 500
DAG-T4
0.10 0.15 0.20 0.25 0.30
NIG-T1
0.0 0.1 0.2 0.3
NIG-T2
0.00 0.05 0.10 0.15 0.20 0.25
NIG-T3
0.00 0.05 0.10 0.15 0.20 0.25
NIG-T4
0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1
DIG-T1
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
DIG-T2
0.3 0.4 0.5 0.6 0.7 0.8
DIG-T3
0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1
DIG-T4
0.00 0.05 0.10 0.15 0.20
DGO-T1
0.0 0.1 0.2 0.3 0.4
DGO-T2
0.05 0.10 0.15 0.20
DGO-T3
0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.11
DGO-T4

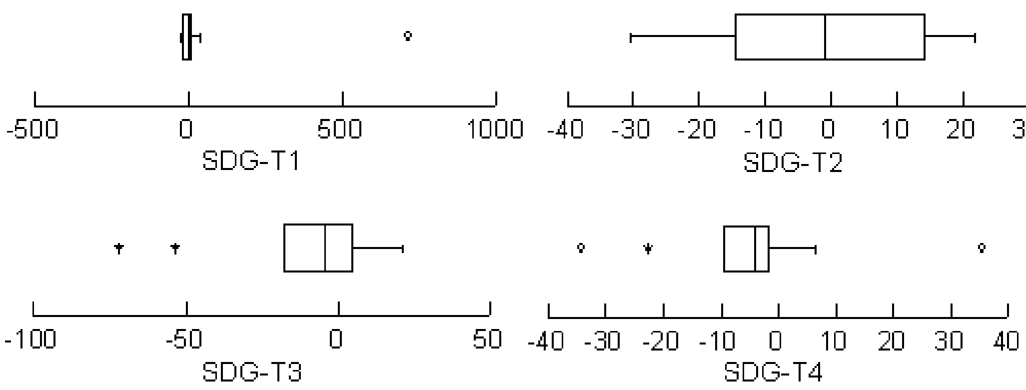


Figure 30. Boxplots of the dependent variables reflecting the gaze behavior.

To examine, whether the detected outliers have a big impact on the inferential statistics' results, a stability analysis has been conducted in a second step. For this purpose, the performed inferential statistics with significant results were repeated ten times, each of which one of the participants has been excluded. The new partial effect sizes have been calculated and are printed in Table 42. Due to the different sample size, they cannot be directly compared to the ones presented in Section 15.3.1.2. However, the standard deviation (see Table 42) of the newly calculated partial effect sizes demonstrate that they only vary with about *SD* = 0.08. The biggest standard deviation (i.e., *SD* = 0.15) was detected regarding the repeated measurement effect of DRG and its two-way interaction effect with M. Although the partial effect sizes vary to some extent, the sizes of the effects are still large and can, as such, be interpreted.

Table 42

Results of the Stability Analyses Analyzing the Impact of Each Participant on the Effect Sizes of the Significant Repeated Measurement Effects of the Gaze Behavior and Their Interaction With the Individual Difference Factors

Source	1	2	3	4	5	6	7	8	9	10	*SD*
NG	0.38	0.37	0.49	0.37	0.32	0.26	0.40	0.44	0.35	0.40	0.06
DG	0.47	0.53	0.38	0.48	0.47	0.48	0.56	0.43	0.29	0.44	0.08
DGxK	0.48	0.54	0.38	0.48	0.46	0.49	0.57	0.43	0.29	0.45	0.08
NRG	0.47	0.59	0.65	0.60	0.63	0.70	0.58	0.61	0.60	0.66	0.06

NRGxB	0.19	0.15	0.19	0.12	0.11	0.40	0.12	0.18	0.16	0.09	0.09
DRG	0.60	0.41	0.48	0.62	0.44	0.38	0.08	0.45	0.43	0.40	0.15
DRGxM	0.61	0.44	0.50	0.64	0.47	0.41	0.09	0.48	0.46	0.43	0.15
DRG	0.60	0.49	0.40	0.45	0.44	0.39	0.13	0.45	0.38	0.38	0.12
DRGxN	0.61	0.51	0.42	0.47	0.46	0.42	0.12	0.47	0.40	0.40	0.13
NPL	0.24	0.32	0.29	0.32	0.32	0.23	0.35	0.37	0.31	0.45	0.06
DPL	0.08	0.09	0.09	0.11	0.20	0.10	0.16	0.04	0.15	0.20	0.05
DAG	0.35	0.34	0.23	0.30	0.34	0.22	0.42	0.31	0.40	0.43	0.07
DAGxF	0.33	0.32	0.21	0.28	0.32	0.21	0.41	0.30	0.38	0.41	0.07
NIG	0.17	0.16	0.13	0.14	0.18	0.16	0.09	0.16	0.15	0.26	0.04
NIGxPR	0.34	0.33	0.35	0.30	0.27	0.31	0.24	0.33	0.31	0.48	0.06
NIG	0.19	0.30	0.16	0.15	0.14	0.16	0.11	0.16	0.15	0.17	0.05
NIGxVE	0.40	0.45	0.41	0.37	0.08	0.38	0.33	0.39	0.38	0.40	0.10
DIG	0.37	0.36	0.39	0.15	0.36	0.31	0.32	0.35	0.37	0.42	0.07
DIGxST	0.35	0.33	0.37	0.11	0.38	0.30	0.28	0.32	0.36	0.39	0.08
DIG	0.75	0.77	0.75	0.69	0.48	0.71	0.72	0.73	0.74	0.72	0.08
DIGxPR	0.73	0.75	0.73	0.65	0.49	0.69	0.69	0.71	0.73	0.70	0.08
DIG	0.35	0.47	0.37	0.29	0.13	0.34	0.33	0.34	0.39	0.49	0.10
DIGxVE	0.32	0.44	0.34	0.22	0.16	0.32	0.27	0.31	0.36	0.44	0.09
SDG	0.13	0.37	0.29	0.38	0.35	0.35	0.34	0.36	0.49	0.46	0.10
SDGxK	0.14	0.35	0.27	0.36	0.33	0.33	0.33	0.34	0.47	0.45	0.09
SDG	0.21	0.39	0.43	0.50	0.44	0.46	0.44	0.47	0.35	0.40	0.09
SDGxV	0.22	0.36	0.41	0.48	0.42	0.43	0.42	0.45	0.32	0.37	0.08

15.3.1.5. Conclusions.

In Section 5.7, an adaptation process of the information acquisition to a new environment has been proposed as well as underlying cognitive processes and determining variables such as intelligence and psychomotor abilities. To test major assumption, research questions were presented (see Section 9) and a study conducted to test the set of hypotheses. For this purpose, the adaptation process has been divided artificially in three phases:

In a first phase, an internal representation of the environment is built requiring the person to gather information about the environment. One way to do so is based on exploratory behavior (see Section 6.4); another important way is to gather information visually. Hence, when confronted with a new environment and in the phase in which the cognitive representation is formulated, the number of gazes executed is increased and decreases with the familiarity of the situation. This, in H^I_1 proposed repeated measurement effect has yielded a significant result, which, however, did not interact significantly with the intelligence measures. In contrast, the average gaze duration does show an interaction with the participants' processing capacity: The average duration of a gaze shows a clear decline overall four practice trials for the participants with greater processing capacity, while the participants with lower values show an initial decline, but a final decrease. The interaction was expected (see H^I_2) as the information processing demands decrease with the familiarity of the situation and it was further expected that this decline is accelerated for those with greater intelligence measures.

This internal representation is also dependent on the activity which is of interest in the environment. This reference to the activity and its consideration when building the cognitive representation is reflected in the data set by the number of task-relevant gazes in relation to the total number of gazes: It decreases linearly (H^I_3), as presumably irrelevant locations are not paid attention to. Again, the interaction with the measures of individual differences is not significant. Instead, the course of the average duration of these task-related in relation to the average duration of any gaze differs for the participants with greater memory and numerical abilities. The information acquisition is reduced for the participants with greater intellectual abilities.

The internal representation allows the actors to mentally simulate the effects of activities and chose the one with the best chances for success. This activity is also reflected in the gaze behavior: When the situation is still unfamiliar, participants plan future activities mentally by looking at the various objects which are required to realize the plan. This anticipatory gaze behavior decreases with the number of practice trials performed, as demonstrated by the inferential analyses executed (see

H^I_5). However, the average duration of the gazes does not change during the adaptation process (but see H^I_6). An interaction effect with the measures of intelligence is neither at hand regarding the number of plans executed nor with the average duration of a plan.

Summarizing, the hypotheses testing the assumptions underlying the first phase of the adaptation process and more specifically, the formation of an internal representation, which is dependent on the task, and the mental simulation of potential ways to achieve the given goal are to some extent confirmed: While most of the dependent variables change during the adaptation process, the influence of the individual differences is limited to the duration of the information acquisition, which, in parallel to the proposed relationships, decreases for the participants with greater intelligence measures to a greater degree.

In the second phase of the adaptation process, the internal representation of the task has been formulated and plans have been defined which are optimal in satisfying the motive underlying the activity of interest. In that stage, anchors are perceived, which are objects pointing to a group of operations, i.e., actions. As these anchors activate a set of operations, so that more information is contained in the optic array. Hence, the average duration of a gaze on an anchor should be longer than the gazes on the other objects (see H^I_7). Such a linear decline has been found for participants with greater figural abilities, while the participants with lower figural abilities showed an initial decline with a final increase. Hence, for the more able participants, the anchor lost its role during the adaptation process and the participants proceeded to the next phase of the adaptation process.

In the third phase proposed, the alignment between gaze behavior and human behavior is getting stronger. The gaze behavior is no longer distracted by providing visual input for building the internal representation and mentally simulating the effects of the operations; the human behavior is no longer aimed at complementing the visually available information. Hence, the number of gazes aimed at the object of interest for the current operation increases or the number of operation-independent gazes decreases in relation to the overall number of gazes performed (see H^I_8). The function of this gaze behavior being aligned with the operations is to provide feedback on the current operation and, if necessary, prepare little adaptations and allow fine-tuning. The few operation-independent gazes still occurring take place, if, the current operation does no longer require the attention and the environment is checked, whether any changes have occurred that might influence the course of the operations. Hence, the number of operation-independent gazes is closely related to the psychomotor abilities of a participant: Participants with greater psychomotor abilities will show a higher pace in their operations, which will provide them less time and less room for executing operation-independent gazes. Such an interaction in the proposed direction has been detected regarding the velocity and precision measures. The relative time required for executing the operation-independent gazes decreases, parallel to their relative number (see H^I_9). This decrease interacts with the participants' steadiness, precision and velocity values and confirms the previously made assumption that the time during which no feedback is required for executing the current operation does determine the number and time available for gazes checking the environment for presumably important changes having an impact on the operation.

The alignment of gazes and behavior is not only tested based on the "not-aligned" number of gazes and their duration, but also based on the duration of gazes on specific objects (see H^I_{10}) and the differences between the start dates of gazes and related operations (see H^I_{11}). As the majority of the gazes are expected to be related to the current operation, the average duration of a gaze on a specific object is determined by the relevance of that object on goal attainment. The relevance of that object has been calculated based on the number of times it has been required for achieving the goal. However, a clear pattern with increasing predictive validity has not been confirmed with the underlying statistics for the one object the hypothesis has been tested with. However, the analyses revealed a significant effect of the difference between the start dates of the gazes and the related operations and an interaction with the processing capacity and the verbal abilities of the participants. For the participants with lower ability measures, the alignment starts at a later stage compared to the participants with greater intelligence values. However, these results must be analyzed with caution, as discussed in Section 15.3.1.3 outliers might have biased this result.

Summarizing, the majority of the hypotheses testing the change of the information acquisition during adaptation and its interaction with the ability measures have been supported. Initially a cognitive representation of the environment is built, which also includes information about the actions and operations to be performed (see also Section 15.3.2). With further practice, anchors point to actions and last, the gaze behavior is aligned with the operations. The intelligence measures did mainly influence the duration of the information acquisition, while an influence on the way of information acquisition was not revealed, except for the change of the differences of the start dates of the gazes and the related operations.

15.3.2. Does the Human Behavior Change According to the Proposed Theory and Does This Change Interact With the Ability Measures?

In this section, the proposed changes of the human behavior and the influence of the ability measures on these changes are analyzed, as proposed in Section 6.4 and 7.2. To yield well-grounded results, four steps are taken: First, the descriptive statistics of the variables of interest and their correlations are analyzed (see Section 15.3.2.1), in order to examine whether the expected effects might be there. The focus is put on analyzing the means, the standard deviations, as well as the minimum and maximum values. Further, bivariate correlations are analyzed. In a second step, the inferential statistics applied are introduced and their results reported (see Section 15.3.2.2). The significant effects are visualized with appropriate scatterplots and line plots. Third, the assumptions underlying these inferential statistics applied will be tested and the impact on the already introduced results discussed (see Section 15.3.2.3). Last, the stability of the results will be analyzed (see Section 15.3.2.4.) and they will be put in relation to the, in Section 6.4 und 7.2 theoretically described processes (see Section 15.3.2.5).

15.3.2.1. Descriptive analyses.

15.3.2.1.1. Basic statistics

Basic descriptive statistics for the dependent variables used for analyzing the change of the human behavior overall trials is given in Table 43 (for the descriptive statistics for the independent variables, see Table 27). As indicated in Table 43, data from 13 participants are available for these variables (see Section 15.2.2.).

As described in H^B_1 – H^B_5 (Section 9), it is expect that the measured variables change overall practice trials, which should be reflected in their means, medians, minimum and maximum values printed in Table 43. A clear decline show these descriptive statistics for NIO (see H^B_1), DO (see H^B_3), and NA (see H^B_5), while for NIO also the standard deviation decreases overall four practice trials. The standard deviations for DO and NA do not show a consistent change in the course of the adaptation process. The opposite pattern, i.e., an increase especially regarding the means and medians, is apparent regarding DIO (H^B_2). NST (see H^B_4) shows a different course: It increases initially but decreases from the third to the fourth practice trial. Hence, an inverted "u"-shaped pattern is at hand.

Table 43

Descriptive Statistics of the Variables Reflecting the Change of the Human Behavior

Variable	*N*	Mean	Median	*SD*	Minimum	Maximum
NIO-T1	13	0.19	0.19	0.08	0.08	0.37
NIO-T2	13	0.15	0.15	0.04	0.06	0.23
NIO-T3	13	0.13	0.12	0.05	0.04	0.20
NIO-T4	13	0.13	0.11	0.06	0.05	0.27
DIO-T1	13	1.50	1.39	0.52	0.90	2.78
DIO-T2	13	1.42	1.34	0.38	0.98	2.21
DIO-T3	13	1.81	1.89	0.76	0.85	3.44
DIO-T4	13	1.77	1.65	0.54	1.07	2.75
DO-T1	13	246.78	253.72	73.80	138.81	388.46
DO-T2	13	218.32	243.83	51.78	128.08	280.99
DO-T3	13	199.55	212.17	62.76	90.18	286.05
DO-T4	13	201.40	168.91	84.88	101.67	343.25
NST-T1	13	9.77	8.00	5.48	3.00	22.00
NST-T2	13	14.92	13.00	9.45	2.00	33.00
NST-T3	13	16.00	14.00	9.96	6.00	36.00

NST-T4	13	11.31	10.00	7.62	3.00	32.00
NA-T1	13	11.92	11.00	3.68	8.00	21.00
NA-T2	13	10.77	11.00	3.44	5.00	16.00
NA-T3	13	8.31	8.00	3.01	4.00	13.00
NA-T4	13	8.46	8.00	4.22	3.00	17.00

15.3.2.1.2. Correlations

The bivariate correlations give valuable information especially about repeated measurement effects: If an effect is at hand, adjacent trials should correlate to a greater degree than do non-adjacent trials (see Guttmann, 1954). In order to analyze this pattern, the correlations between the variables involved in each of the conducted analyses are given in Appendix L and discussed in the following.

Correlations between the variables involved when testing the, in $H^B{}_1$ expected effects

Table L1 in Appendix L gives the bivariate correlations between the variables involved in the inferential tests applied to analyze $H^B{}_1$. These correlations show, first, a relatively clear simplex pattern: NIO-T2 and NIO-T3 correlate, for example, to *r* = .79 ($p < .01$), while NIO-T1 only correlates with NIO-T3 to *r* = .14 (n.s.). However, NIO-T2 and NIO-T4 correlate quite high, i.e., to *r* = .52 (n.s.). Second, the correlations between the intelligence factors and the repeated measurements were analyzed: B, for example, shows increasing correlations with NIO. It starts with *r* = -.18 and ends with *r* = -.48. The same general tendency is apparent regarding V, while the correlations with K follow the shape of an inverted “u”.

Correlations between the variables involved when testing the, in $H^B{}_2$ expected effects

A similar pattern is at hand regarding the bivariate correlations between the variables included in the analysis testing $H^B{}_2$ (see Table L2, Appendix L): The adjacent trials of DIO correlate to a greater extent than do the non-adjacent trials. Hence, a repeated measurement effect is likely (but see Section 15.3.2.1.1). For example, DIO-T2 and DIO-T3 correlate to *r* = .52 (n.s.), while DIO-T1 and DIO-T3 only correlate to *r* = -.06 (n.s.). The correlational patterns between DIO and the intelligence factors show that, e.g., M has a decreasing impact on DIO. The correlations decrease from $r = .64$ initially to $r = .01$. The correlations with N show a similar change overall four practice trials.

Correlations between the variables involved when testing the, in H^B_3 expected effects

The variables included in the analyses testing H^B_3 referred to DO and the intelligence factors. A simplex pattern typical for repeated measurement effects is at hand for DO (see Appendix L, Table L3): For example, DO-T1 correlates with DO-T2 to $r = .89$ ($p < .01$) and DO-T1 and DO-T4 correlate to $r = .76$ ($p < .01$). However, it is in contrast to the expected simplex pattern that the third and fourth practice trial correlate only to $r_{DO\text{-}T3,\ DO\text{-}T4} = .69$ ($p < .01$). The correlations of DO with the intelligence factors are nearly all negative, some reach a significance level of $p < .01$. F, for example, correlates significantly ($p < .05$) with DO overall practice trials in a negative way: The bigger F, the smaller DO. In Section 15.3.2.3., inferential statistics will be applied to check whether the repeated measurement effect reaches the level of significance.

Correlations between the variables involved when testing the, in H^B_4 expected effects

In H^B_4, an inverted "u"-shaped course of NST is expected, which is influenced by the participants' intelligence and psychomotor abilities. The correlations displayed in Table L4 (Appendix L), show a clear simplex pattern indicating that an effect of the repeated measurements is at hand: While NST-T2 and NST-T3 correlate to $r = .79$ ($p < .01$) and NST-3 and NST-T4 to $r = .74$ ($p < .01$), NST-T2 and NST-T4 only correlate to $r = .63$ ($p < .05$) respectively. The correlations between the intelligence and psychomotor abilities and the repeated measurements of NST demonstrate two patterns: The psychomotor abilities show decreasing correlations with NST, while most intelligence variables show an inverted "u"-shaped change of the correlations. For example, the correlation between PR and NST decreases from $r = .35$ (n.s.) to $r = -.48$ (n.s.) and the one between VE and NST from $r = .47$ (n.s.) to r = -.19 (n.s.). An example for the inverted "u"-shaped pattern is the relationship between B and NST: The correlation between B and NST-T1 starts with $r = .01$ (n.s.), the one with NST-T2 increases to $r = -.51$ (n.s.) and then decreases to $r = -.15$ (n.s.). Similar patterns are there, for example, for M, N, and F.

Correlations between the variables involved when testing the, in $H^B{}_5$ expected effects

The last hypothesis, i.e., $H^B{}_5$, expects an effect of the repeated measurements of NA and an interaction between this effect and the measured intelligence factors. The first would result in a typical correlation pattern, i.e., the simplex, with adjacent trials correlating to a greater degree compared to the non-adjacent trials. The correlations given in Table L5 (Appendix L) do not show a clear simplex: For example, the second and third practice trial correlate highly ($r_{NA\text{-}T2,NA\text{-}T3} = .60$, $p < .05$), but the third and fourth practice trial correlate only to $r_{NA\text{-}T3,NA\text{-}T4} = .07$ (n.s.). The correlations with the six intelligence variables are generally speaking negative, i.e., the greater the intelligence, the smaller the number of actions performed, which runs parallel to the theory (see Section 9).

15.3.2.2. Inferential analyses.

In this section, the results of the inferential statistics applied to test the in Section 9 introduced hypotheses are presented.

Inferential analyses testing the, in $H^B{}_1$ expected effects

To test the presence of a repeated measurement effect of NIO and the two-way interaction effect between the measured intelligence factors and NIO (as proposed in $H^B{}_1$), general linear model analyses were performed with repeated measurements. More specifically, NIO-T1, NIO-T2, NIO-T3, and NIO-T4 were included in the analyses as dependent variables, CV1 and CV2 as control variables, and one of the intelligence factors as dependent variable in each analysis. The results of these analyses are given in Table 44.

Table 44

Results of the General Model Analyses Performed to Test the Repeated Measurement Effect of NIO and its Interaction With the Intelligence Factors as Expected in $H^B{}_1$

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				
NIO	3	27	1.01	.40	.38	.40	0.10	0.01
NIOxK	3	27	0.88	.46	.42	.46	0.09	0.00

NIO	3	27	0.20	.90	.80	.89	0.02	0.00
NIOxB	3	27	0.26	.85	.75	.85	0.03	0.00
NIO	3	27	0.68	.57	.50	.56	0.07	0.00
NIOxM	3	27	0.49	.70	.60	.68	0.05	0.00
NIO	3	27	0.04	.99	.95	.99	0.00	0.00
NIOxV	3	27	0.02	.99	.97	.99	0.00	0.00
NIO	3	27	0.28	.84	.73	.83	0.03	0.00
NIOxN	3	27	0.21	.89	.79	.88	0.02	0.00
NIO	3	27	0.52	.67	.59	.67	0.06	0.00
NIOxF	3	27	0.38	.77	.67	.77	0.04	0.00

The results given in Table 44 indicate no significant effects, i.e., the individual differences in the participant's intelligence do not predict the course of the repeated measurements and there is also no change overall practice trials regarding NIO. However, the latter could be the case because of the small sample size. As discussed in Section 15.2.2, the study's power, i.e., the probability of detecting a, in the real world probably existing effect was reduced to the small sample size (see Section 15.2.2). Hence, the non-significant results might have been caused by lacking power. In order to increase the power, another general linear model analysis has been performed only with NIO-T1, NIO-T2, NIO-T3, and NIO-T4 as dependent variables and CV1 and CV2 respectively as control variables. The results of this single analysis are introduced in Table 45.

Table 45

Results of the Single General Linear Model Analysis Performed to Test the Repeated Measurement Effect of NIO

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
Within Subject Variance								
NIO	3	30	5.07	.01**	.02*	.01**	0.34	0.28
Polynominal Test of Order 1								
NIO	1	10	10.74	.01**	-	-	0.52	0.46

			Polynominal Test of Order 2					
NIO	1	10	1.59	.23	-	-	0.14	0.05
			Polynominal Test of Order 3					
NIO	1	10	0.02	.89	-	-	0.00	0.00

Note. $^{**}p < .01$. $^{*}p < .05$.

The results of this single analysis (see Table 45) reveal a repeated measurement effect with F (3, 30) = 5.07, which is significant at $p < .01$. The detected partial effect is with $f^2 = 0.34$ large according to Cohen's classification (1988, 1992). The polynominal tests performed show that the effect follows a linear shape. Its linear component is significant with F (1, 10) = 10.74 ($p < .01$). The scatterplot (Figure 31) demonstrate a clear, linear decline of NIO overall practice trials.

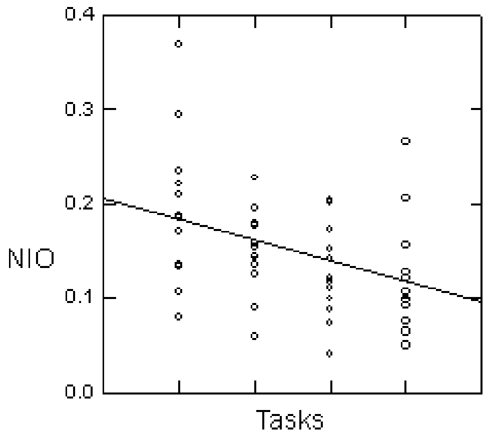


Figure 31. Scatterplot with a linear smoother showing the change of NIO overall four practice trials.

<u>Inferential analyses testing the, in H^B_2 expected effects</u>

To test the, in H^B_2 expected repeated measurement effect of DIO and its interaction with the intelligence factors, six general linear model analyses have been performed with DIO-T1, DIO-T2, DIO-T3, and DIO-T4 as dependent variables and one intelligence factor in each analyses as an independent variable. Both control variables were excluded, as they did not account for a significant part of the dependent variables' variance. The analyses' results are given in Table 46.

Table 46

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DIO and its Interaction With the Intelligence Factors as Expected in $H^B{}_2$

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				
DIO	3	33	0.15	.93	.90	.93	0.01	0.00
DIOxK	3	33	0.21	.89	.86	.89	0.02	0.00
DIO	3	33	0.47	.70	.07	.70	0.04	0.00
DIOxB	3	33	0.62	.60	.58	.60	0.05	0.00
DIO	3	33	1.16	.34	.34	.34	0.10	0.01
DIOxM	3	33	1.02	.40	.40	.39	0.09	0.00
DIO	3	33	0.42	.74	.74	.74	0.04	0.00
DIOxV	3	33	0.55	.65	.65	.65	0.05	0.00
DIO	3	33	1.19	.33	.33	.33	0.10	0.02
DIOxN	3	33	1.13	.35	.35	.35	0.09	0.01
DIO	3	33	0.06	.97	.98	.98	0.01	0.00
DIOxF	3	33	0.06	.98	.97	.97	0.01	0.00

The results given in Table 46 do neither reveal a significant repeated measurement effect of DIO, nor a significant interaction effect of it with the measured intelligence factors. Parallel to the procedure taken when testing NIO ($H^B{}_1$), another general model analysis has been performed only with DIO-T1, DIO-T2, DIO-T3, and DIO-T4 as dependent variables. The results of this single analysis are given in Table 47.

Table 47

Results of the Single General Analysis Performed to Test the Repeated Measurement Effect of DIO

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				

DIO	3	36	2.14	.11	.13	.11	0.15	0.08

In contrast to the analyses performed to test $H^B{}_2$, the results of the single analysis (see Table 47) also do not reach the level of significance (*F* (3, 36) = 2.14, *p* = .11). Hence, DIO does not change in the course of the adaptation process.

Inferential analyses testing the, in $H^B{}_3$ expected effects

To test $H^B{}_3$, general linear model analyses were executed with DO-T1, DO-T2, DO-T3, and DO-T4 as dependent variables, CV1 as a control variable and the intelligence factors as independent variables, however, each included in separate analyses. CV2 was excluded, as it did not account for a significant part of the dependent variables' variance. Due to the small sample size and associated problems with lacking power (see Section 10), it was aimed at keeping the number of variables included in the analyses small, in order to be able to detect the – in the real world – possibly existing effects. The results of the six general linear model analyses are presented in Table 48.

Table 48

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DO and its Interaction With the Intelligence Factors as Expected in $H^B{}_3$

Source	df_s	df_e	*F*	*p*	G-G	H-F	f^2	ε^2
			Within Subject Variance					
DO	3	30	4.08	.02*	.03*	.02*	0.29	0.22
DOxK	3	30	4.14	.01**	.02*	.01*	0.31	0.23
DO	3	30	1.31	.28	.29	.29	0.12	0.03
DOxB	3	30	1.61	.21	.22	.21	0.14	0.05
DO	3	30	1.50	.24	.25	.24	0.13	0.04
DOxM	3	30	1.97	.14	.17	.15	0.17	0.08
DO	3	30	2.40	.09	.11	.09	0.19	0.11
DOxV	3	30	2.79	.05*	.08	.06	0.22	0.14
DO	3	30	1.48	.24	.25	.24	0.13	0.04

DOxN	3	30	1.96	.14	.17	.15	0.16	0.08
DO	3	30	2.30	.10	.12	.10	0.19	0.11
DOxF	3	30	2.57	.07	.09	.07	0.21	0.12
Polynominal Test of Order 1								
DO	1	10	4.39	.06	-	-	0.31	0.23
DOxK	1	10	6.02	$.03^{*}$	-	-	0.38	0.31
DO	1	10	2.95	.12	-	-	0.23	0.15
DOxV	1	10	4.83	$.05^{*}$	-	-	0.33	0.26
Polynominal Test of Order 2								
DO	1	10	4.14	.07	-	-	0.29	0.22
DOxK	1	10	3.81	.08	-	-	0.28	0.20
DO	1	10	2.30	.16	-	-	0.19	0.11
DOxV	1	10	1.99	.19	-	-	0.17	0.08
Polynominal Test of Order 3								
DO	1	10	3.03	.11	-	-	0.23	0.16
DOxK	1	10	3.10	.11	-	-	0.24	0.16
DO	1	10	1.49	.25	-	-	0.13	0.04
DOxV	1	10	1.56	.24	-	-	0.14	0.05

Note. $^{*}p < .05$. $^{**}p < .01$.

As the results given in Table 48 demonstrate, the repeated measurement effect of DO and the two-way interaction between DO and K are significant (F (3, 30) = 4.08, $f^2 = 0.29$, $p < .05$ and F (3, 30) = 4.14, $f^2 = 0.31$, $p < .01$ respectively), as is the interaction of DO with V (F (3, 30) = 2.79, $f^2 = 0.22$, $p < .05$). The interaction effect between DO and K is classified as large, while the repeated measurement effect of DO and the interaction with F are judged in between large and medium-sized according to the conventions developed by Cohen (1988, 1992). The polynominal tests of linear order are significant for the interaction effect of DO and K (F (1, 10) = 6.02, $p < .05$) and for the interaction effect between DO and V (F (1, 10) = 4.83, $p < .05$), whereas the repeated measurement effect of DO just misses the level of significance (F (1, 10) = 4.39, $p = .06$). Still, the scatterplot with a linear smoother and the line plots showing the different shapes of the adaptation processes of the participants with greater and smaller K and V abilities (dichotomized artificially) are presented in Figure 32. The scatterplot demonstrates that DO decreases with the number of the practice trials performed, while the line plot shows the different shapes of the two groups of participants, derived by artificial dichotomization. The participants with greater ability levels start at a lower intercept and the difference between the two groups increases during the adaptation process.

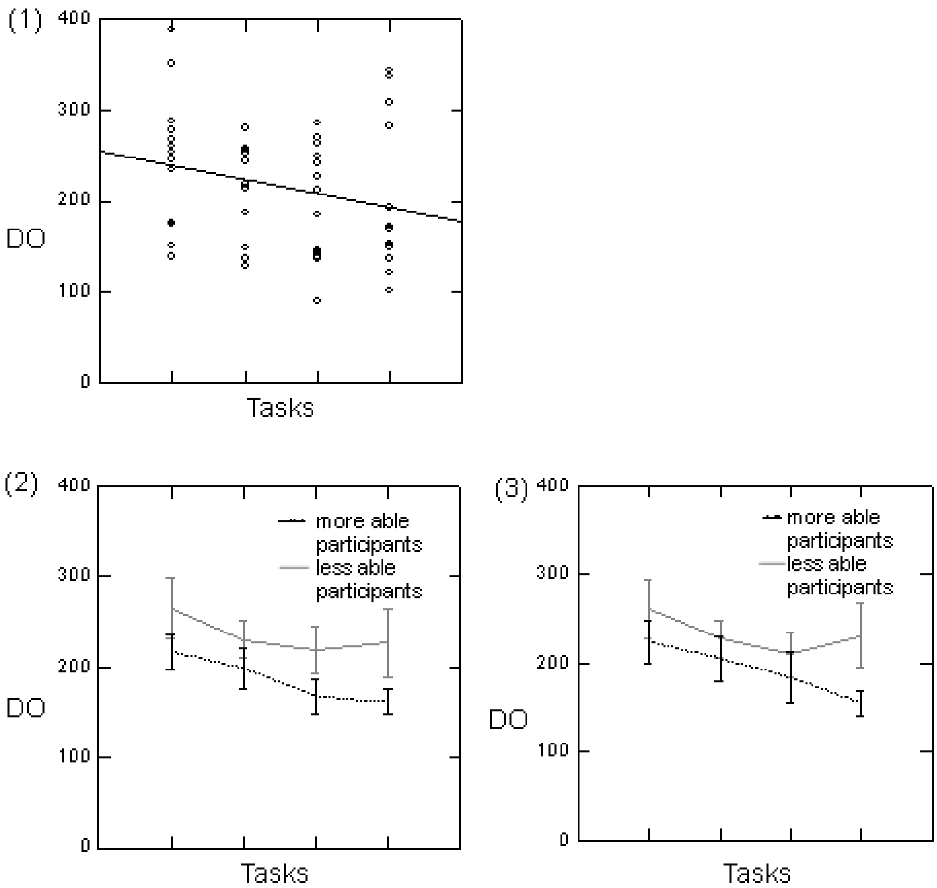


Figure 32. (1) Scatterplot with a linear smoother showing the change of DO overall four practice trials. (2) Line plot with standard error bars showing the change of DO for the participants with lower (drawn-through line) and greater (dotted line) K abilities. (3) Line plot with standard error bars showing the change of DO for the participants with lower (drawn-through line) and greater (dotted) V abilities.

Inferential analyses testing the, in H^B_4 expected effects

The change of NST overall practice trials and interaction of this repeated measurement effect with the intelligence factors and the psychomotor abilities, as expected according to $H^B{}_4$, was tested by conducting general linear model analyses with NST-T1, NST-T2, NST-T3, and NST-T4 as dependent variables, CV1 as control variable, and one ability variable as an independent variable. The approach to use one analysis to test each interaction of the repeated measurements of NST and a variable reflecting individual differences in relevant abilities was taken due to the small sample size (see Section 15.1). The results are given in Table 49.

Table 49

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NST and its Interaction With the Intelligence and Psychomotor Factors as Expected in $H^B{}_4$

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				
NST	3	30	1.37	.27	.27	.27	0.12	0.03
NSTxK	3	30	1.05	.38	.37	.38	0.10	0.00
NST	3	30	4.72	.01**	.01**	.01**	0.32	0.25
NSTxB	3	30	3.63	.02*	.03*	.02*	0.15	0.19
NST	3	30	3.40	.03*	.04*	.03*	0.25	0.18
NSTxM	3	30	2.73	.06	.07	.06	0.21	0.14
NST	3	30	4.11	.02*	.02*	.02*	0.29	0.22
NSTxV	3	30	3.28	.03*	.04*	.03*	0.25	0.17
NST	3	30	4.00	.02*	.03*	.02*	0.29	0.21
NSTxN	3	30	3.29	.03*	.05*	.03*	0.25	0.17
NST	3	30	1.66	.20	.21	.20	0.14	0.06
NSTxF	3	30	1.22	.32	.32	.32	0.10	0.00
NST	3	30	2.59	.07	.09	.07	0.21	0.13
NSTxST	3	30	1.20	.33	.33	.33	0.11	0.02
NST	3	30	6.37	.00**	.00**	.00**	0.39	0.33
NSTxPR	3	30	4.09	.02*	.02*	.02*	0.29	0.22

NST	3	30	5.74	.00**	.01*	.00**	0.37	0.30
NSTxVE	3	30	2.99	.05*	.06	.05*	0.23	0.15
NST	3	30	4.75	.01*	.01*	.01*	0.32	0.25
NSTxTP	3	30	2.23	.11	.12	.11	0.18	0.10
Polynominal Test of Order 1								
NST	1	10	0.00	.97	-	-	0.00	0.00
NSTxB	1	10	0.04	.86	-	-	0.00	0.00
NST	1	10	0.64	.44	-	-	0.06	0.00
NSTxM	1	10	0.41	.54	-	-	0.04	0.00
NST	1	10	0.29	.61	-	-	0.03	0.00
NSTxV	1	10	0.13	.72	-	-	0.01	0.00
NST	1	10	2.65	.14	-	-	0.21	0.13
NSTxN	1	10	2.17	.17	-	-	0.18	0.10
NST	1	10	0.01	.91	-	-	0.00	0.00
NSTxPR	1	10	0.35	.57	-	-	0.03	0.00
NST	1	10	0.00	.97	-	-	0.00	0.00
NSTxVE	1	10	0.56	.47	-	-	0.05	0.00
NST	1	10	0.53	.49	-	-	0.05	0.00
NSTxTP	1	10	0.01	.91	-	-	0.00	0.00
Polynominal Test of Order 2								
NST	1	10	11.52	.01*	-	-	0.54	0.49
NSTxB	1	10	8.62	.02*	-	-	0.46	0.30
NST	1	10	7.36	.02*	-	-	0.42	0.25
NSTxM	1	10	5.89	.04*	-	-	0.37	0.31
NST	1	10	10.94	.01*	-	-	0.52	0.47
NSTxV	1	10	8.77	.01*	-	-	0.47	0.37
NST	1	10	7.95	.02*	-	-	0.44	0.39
NSTxN	1	10	6.46	.03*	-	-	0.39	0.33
NST	1	10	19.13	.00**	-	-	0.66	0.62
NSTxPR	1	10	12.02	.01*	-	-	0.55	0.50

NST	1	10	14.75	.00**	-	-	0.60	0.56
NSTxVE	1	10	7.34	.02*	-	-	0.42	0.37
NST	1	10	11.27	.01**	-	-	0.53	0.48
NSTxTP	1	10	5.40	.04*	-	-	0.35	0.29
Polynominal Test of Order 3								
NST	1	10	0.90	.37	-	-	0.08	0.00
NSTxB	1	10	0.92	.36	-	-	0.08	0.00
NST	1	10	0.53	.48	-	-	0.05	0.00
NSTxM	1	10	0.54	.48	-	-	0.05	0.00
NST	1	10	0.08	.79	-	-	0.01	0.00
NSTxV	1	10	0.08	.79	-	-	0.01	0.00
NST	1	10	0.43	.53	-	-	0.04	0.00
NSTxN	1	10	0.44	.53	-	-	0.04	0.00
NST	1	10	0.04	.84	-	-	0.00	0.00
NSTxPR	1	10	0.04	.84	-	-	0.00	0.00
NST	1	10	0.03	.87	-	-	0.00	0.00
NSTxVE	1	10	0.04	.85	-	-	0.00	0.00
NST	1	10	0.00	.99	-	-	0.00	0.00
NSTxTP	1	10	0.00	.99	-	-	0.00	0.00

Note. $^{**}p < .01$. $^{*}p < .05$.

The analyses, whose results are given in Table 49, reveal the following significant repeated measurement of NST and interaction effects of it with the intelligence measures:

- The repeated measurement effect of NST and its interaction with B is significant with F (3, 30) = 4.72 (p < .01) and F (3, 30) = 3.63 (p < .05) respectively. The repeated measurement effect is of quadratic shape according to the results of the polynominal tests performed (F (1, 10) = 11.51, p < .01), as well as its interaction with B (F (1, 10) = 8.62, p < .05). The size of the partial repeated measurement effect is with f^2 = 0.32 large according to Cohen's (1988, 1992) classification, as is its the interaction with B (f^2 = 0.46).

- The repeated measurement effect of NST is significant with F (3, 30) = 3.40 ($p < .05$) in the analysis testing also its interaction with M. However, the interaction effect does not reach the level of significance. The size of the detected partial effect is in between large and medium-sized according to Cohen (1988, 1992), as it reaches a level of $f^2 = 0.25$. The polynominal test of quadratic order is significant with F (1, 10) = 7.36 ($p < .05$).
- Both, the repeated measurement of NST and its two-way interaction with V is significant with F (3, 30) = 4.11 ($p < .05$) and F (3, 30) = 3.28 ($p < .05$). With $f^2 = 0.29$ and $f^2 = 0.25$ respectively the effects judged in between middle-sized and large, according to Cohen (1988, 1992). Both effects show a quadractic course according to the polynominal tests performed (F (1, 10) = 10.94, $p < .05$ and F (1, 10) = 8.77, $p < .05$).
- Last, significant are the repeated measurement effect of NST and its interaction with N in the fifth analysis performed: The repeated measurement effect is significant with F (3, 30) = 4.00 ($p < .05$) and the interaction with F (3, 30) = 3.29 ($p < .05$). Again, both effects show a quadratic course (F (1, 10) = 7.95, $p < .05$ and F (1, 10) = 6.46, $p < .05$) and their sizes are judged in between middle and large ($f^2 = 0.29$ and $f^2 = 0.25$ respectively).

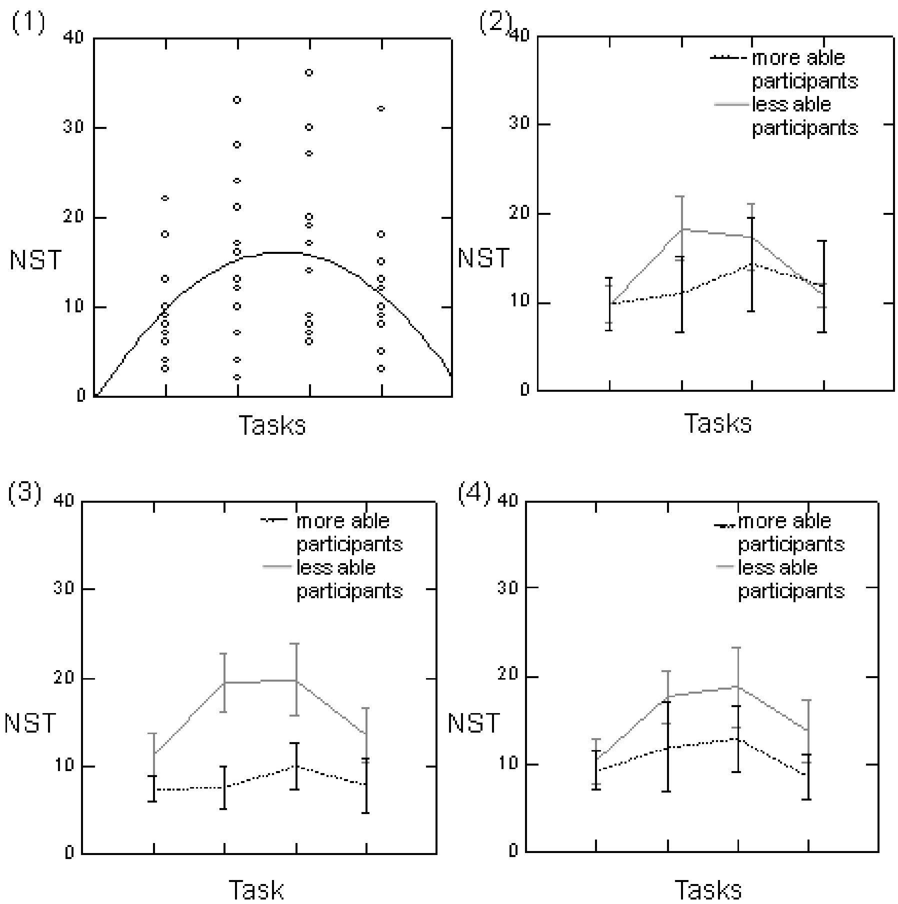
Significant interaction effects and repeated measurement effects have also been found regarding analyses in which the psychomotor test results were included as independent variables (see Table 49):

- Both, the repeated measurement of NST and its interaction with PR are significant with F (3, 30) = 6.37 ($p < .01$) and F (3, 30) = 4.09 ($p < .05$) respectively. The partial repeated measurement effect is large ($f^2 = 0.39$) according to Cohen's (1988, 1992) classification; whereas the partial interaction effect is with $f^2 = 0.29$ between medium-sized and large. The polynominal tests reveal that both effects' changes follow a quadratic course (F (1, 10) = 19.13, $p < .01$ and F (1, 10) = 12.02, $p < .05$ respectively).
- A similar pattern is found for the analysis applied for testing the interaction with VE. Both, the repeated measurement of NST is significant (F (3, 30) = 5.74, $p < .01$), as is its interaction with VE (F (3, 30) = 2.99, $p < .05$). The

partial effect of the repeated measurements (f^2 = 0.37) is judged as large; whereas the partial interaction effect is smaller (f^2 = 0.23). Both changes are shaped quadratically (F (1, 10) = 14.75, p < .01 and F (1, 10) = 7.34, p < .05).

- Last, the repeated measurement effect of NST was significant in the analysis including TP (F (3, 30) = 4.75, p < .01); whereas its interaction effect with TP failed to reach the level of significance. The partial repeated measurement effect yields a significant polynominal test of quadratic order (F (1, 10) = 11.27, p < .01) and is with f^2 = 0.32 large, according to Cohen (1988, 1992).

Figure 33 depicts these significant effects graphically. Its scatterplot reveals that NST shows a course like an inverted "u": It increases initially and decreases again in the later trials. This shape is developed to a greater degree consistently for the, regarding B, V, N, PR, and VE less able participants. The shape for the more able participants resembles more a linear shape, which increases slightly.



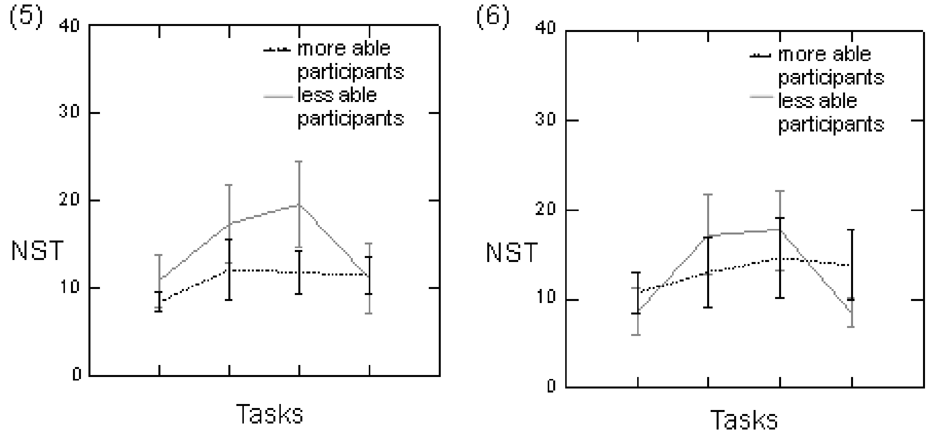


Figure 33. (1) Scatterplot with a quadratic smoother showing the change of NST overall four practice trials. (2) Line plot with standard error bars showing the change of NST for the participants with lower (drawn-through line) and greater (dotted line) B abilities. (3) Line plot with standard error bars showing the change of NST overall four practice trials for the participants with greater (dotted line) and lower (drawn-through line) V abilities. (4) Line plot with standard error bars showing the change of NST overall four practice trials for the participants with greater (dotted line) and lower (drawn-through line) N abilities. (5) Line plot with standard error bars showing the change of NST for the participants with greater (dotted line) and lower (drawn-through line) PR values. (6) Line plot with standard error bars showing the change of NST overall four practice trials for the participants with greater (dotted line) and lower (drawn-through line) VE abilities.

Inferential analyses testing the, in H^B_5 expected effects

In order to test the last hypothesis, i.e., H^B_5, general linear model analyses were performed with NA-T1, NA-T2, NA-T3, and NA-T4 as dependent variables, CV1 and CV2 as control variables, and one intelligence factor as an independent variable in each analysis. Hence, six general linear model analyses were performed and their results are given in Table 50.

Table 50

Results of the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NA and its Interaction With the Intelligence Factors as Expected in H^B_5

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				
NA	3	27	0.18	.91	.88	.91	0.02	0.00
NAxK	3	27	0.16	.92	.89	.92	0.02	0.00
NA	3	27	1.94	.15	.17	.15	0.18	0.09
NAxB	3	27	1.95	.15	.16	.15	0.18	0.09
NA	3	27	0.79	.51	.50	.51	0.08	0.00
NAxM	3	27	0.67	.58	.56	.58	0.07	0.00
NA	3	27	0.63	.60	.57	.60	0.07	0.00
NAxV	3	27	0.60	.62	.59	.62	0.06	0.00
NA	3	27	0.32	.81	.77	.81	0.04	0.00
NAxN	3	27	0.30	.83	.79	.83	0.03	0.00
NA	3	27	0.29	.84	.80	.84	0.03	0.00
NAxF	3	27	0.23	.88	.84	.88	0.03	0.00

The results given in Table 50 are all not significant (with $p < .05$), which could have been caused by the low power of the study (see Section 15.2.2). Hence, a possibly existing effect might not have been detected based on the analyses performed. As the results in Table 50 show, the two-way interaction effects do not account for lots of variance of the dependent variables and the inclusion of the independent variables might have made detecting a possibly existing effect of the repeated measurements hardly possible. This is why a single general linear model analysis has been performed only including NA-T1, NA-T2, NA-T3, and NA-T4 as dependent and CV1 and CV2 as control variables. Its results are given in Table 51.

Table 51

Results of the Single General Model Analysis Performed to Test the Repeated Measurement Effect of NA

Source	df_s	df_e	F	p	G-G	H-F	f^2	ε^2
				Within Subject Variance				
NA	3	30	3.60	$.03^*$	$.04^*$	$.03^*$	0.27	0.19

			Polynominal Test of Order 1					
NA	1	10	8.00	.02*	-	-	0.45	0.39
			Polynominal Test of Order 2					
NA	1	10	0.64	.44	-	-	0.06	0.00
			Polynominal Test of Order 3					
NA	1	10	1.88	.20	-	-	0.16	0.07

Note. * $p < .05$.

The results given in Table 51 reveal a significant repeated measurement effect of NA with F (3, 30) = 3.60 ($p < .05$) and $f^2 = 0.27$. According to Cohen's classification (1988, 1992), this effect is judged in between middle-sized and large. As the polynominal tests show, the repeated measurements show a linear effect (F (1, 10) = 8.00, $p < .05$), which is depicted in Figure 34.

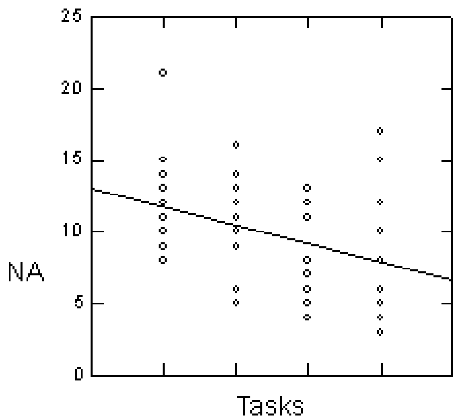


Figure 34. Scatterplot with a linear smoother showing the change of NA overall four practice trials.

15.3.2.3. Test of the assumptions.

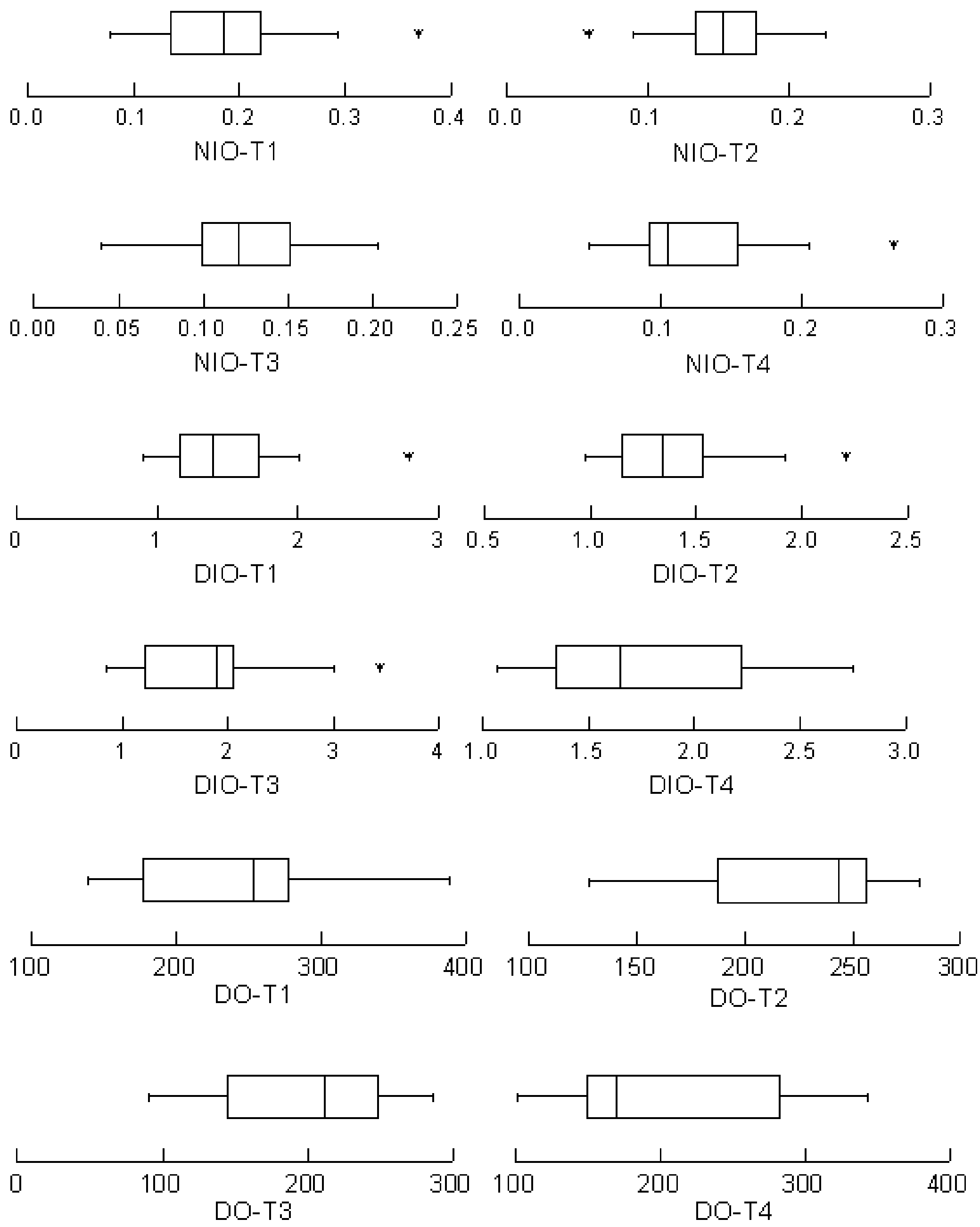
The in Section 15.3.2.2 given results can only be interpreted as stated, if the assumptions underlying the applied statistics are valid (see also Section 15.1). For this purpose, the scatterplots of the residuals were plotted against each independent variable and the predicted values, the scatterplots between the residuals and the ordered values were analyzed to check homoscedasticity, the independence of the residuals and the normal distribution of the residuals for each analysis conducted. These plots showed minor irregularities due to the small sample size. However, as Scheffé (1959) and Cohen and Cohen (1983) state, the *F*-distribution is robust to small violations of the assumptions underlying it. To complement the visual impressions from the plots, the Mauchly-Tests have been performed for each analysis whose results were introduced in Section 15.3.2.2. The Mauchly-Test tests the sphericity assumption and its results are given in Appendix M. The results show that the sphericity assumption was violated regarding the analysis only testing the repeated measurement effect of NIO ($\chi^2 = 12.92$, $p = .03$). Hence, again, the degrees of freedom need to be adjusted based on the G-G and H-F formulas. The resulting probability values (G-G = .02 and H-F = .01, see Table 45) are still significant with $p < .05$. Hence, the violation of the sphericity assumption does not affect the interpretation given in Section 15.3.2.2.

As the Mauchly-Test tends not to show violations of the sphericity assumption for small sample sizes (see e.g., Rasch, Friese, Hofmann & Naumann, 2006), still, the results of the analyses showing insignificant results for the Mauchly-Test need to be interpreted carefully.

15.3.2.4. Stability of the results.

To test the results' stability, the data set was checked regarding multicollinearity, possible suppressor effects, and irregularities in the sample.
More specifically, to detect multicollinearity the correlations given in Appendix L were analyzed whether any is bigger than $r = .90$. This is not the case, so that multicollinearity is not expected to be a problem in any of the analyses performed to test the change of human behavior during the repeated measurements and its interaction with the measured abilities. The same is the case regarding suppressor effects: The analysis of the correlations (given in Appendix L) show that the independent variables included in the various analyses, do not correlate to such an extent to cause a suppressor effect.

Another problem, which might reduce the stability of the given results, is irregularities in the sample. Due to the small sample size, this is a crucial point. To detect outliers, boxplots for the variables used as dependent variables are given in Figure 35, the ones used as independent and control variables were already printed in Figure 29.



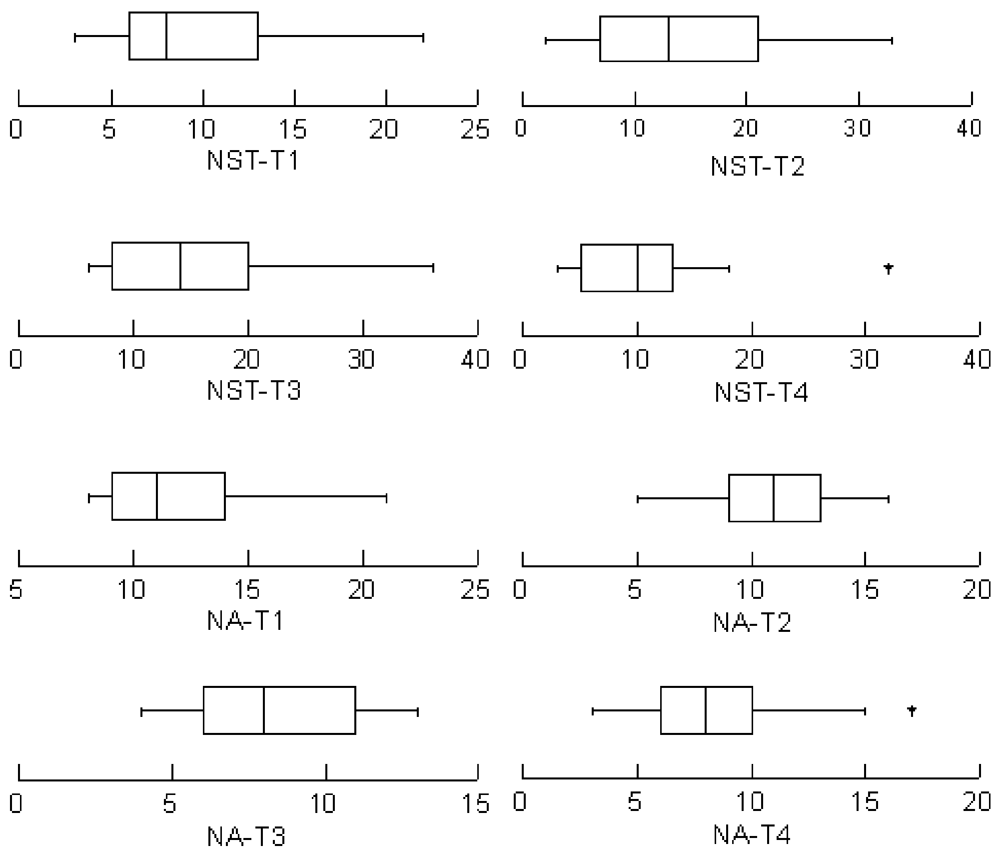


Figure 35. Boxplots of the dependent variables reflecting the human behavior.

Some variables show outliers (e.g., NA-T4); however, there are no consistent patterns, i.e., participants who have extreme values on many variables. Based on the results of the boxplots, no participant was excluded from the analyses at hand.

To complement these results and examine whether a participant had a big influence on the results, the significant analyses described in Section 15.3.2.2 have been repeated 13 times – each time another participant was excluded from the analyses. The partial effect sizes were calculated as was their standard deviations (see Table 52). The standard deviations are relatively small, smaller than the ones introduced in Section 15.3.1.4 for the change of the gaze behavior and its interaction with the relevant abilities, so that excluding any participant does not have a big impact on the results. Hence, irregularities, which have a negative impact on the stability of the results, are not apparent in this respect.

Table 52

Results of the Stability Analyses Analyzing the Impact of Each Participant on the Effect Sizes of the Significant Repeated Measurement Effects of the Behavior and Their Interaction With the Individual Difference Factors

Source	1	2	3	4	5	6	7	8	9	10	11	12	13	*SD*
NIO	0.36	0.32	0.34	0.33	0.31	0.35	0.31	0.37	0.39	0.26	0.36	0.31	0.38	0.03
DO	0.26	0.29	0.20	0.27	0.39	0.29	0.30	0.33	0.32	0.28	0.26	0.32	0.31	0.04
DOxK	0.28	0.30	0.22	0.30	0.40	0.30	0.31	0.35	0.33	0.31	0.27	0.33	0.32	0.04
DO	0.17	0.19	0.17	0.19	0.29	0.21	0.24	0.21	0.22	0.17	0.14	0.20	0.19	0.04
DOxV	0.19	0.21	0.19	0.23	0.31	0.23	0.26	0.24	0.24	0.20	0.16	0.22	0.21	0.04
NST	0.27	0.29	0.34	0.38	0.30	0.33	0.36	0.34	0.27	0.36	0.33	0.36	0.30	0.03
NSTxB	0.23	0.24	0.28	0.32	0.26	0.28	0.31	0.28	0.21	0.30	0.27	0.30	0.26	0.03
NST	0.20	0.28	0.30	0.27	0.23	0.37	0.31	0.26	0.09	0.29	0.26	0.28	0.24	0.07
NSTxM	0.17	0.24	0.26	0.22	0.19	0.33	0.26	0.22	0.07	0.25	0.22	0.24	0.20	0.06
NST	0.20	0.25	0.33	0.33	0.26	0.34	0.35	0.32	0.24	0.31	0.32	0.32	0.28	0.04
NSTxV	0.17	0.21	0.28	0.28	0.22	0.29	0.30	0.27	0.19	0.27	0.28	0.27	0.24	0.04
NST	0.24	0.27	0.29	0.31	0.24	0.44	0.34	0.29	0.16	0.31	0.30	0.31	0.29	0.06
NSTxN	0.21	0.23	0.26	0.27	0.20	0.40	0.30	0.25	0.12	0.27	0.26	0.27	0.26	0.06
NST	0.33	0.42	0.40	0.42	0.39	0.32	0.47	0.46	0.40	0.43	0.42	0.43	0.41	0.04
NSTxPR	0.24	0.31	0.30	0.32	0.29	0.23	0.37	0.37	0.28	0.34	0.32	0.33	0.32	0.04

NST	0.27	0.38	0.37	0.43	0.35	0.30	0.43	0.40	0.38	0.39	0.38	0.40	0.35	0.04
NSTxVE	0.17	0.23	0.24	0.30	0.21	0.17	0.29	0.27	0.21	0.27	0.23	0.26	0.23	0.04
NST	0.24	0.29	0.33	0.40	0.30	0.33	0.37	0.32	0.32	0.34	0.35	0.34	0.32	0.04
NSTxTP	0.12	0.14	0.19	0.27	0.15	0.20	0.22	0.18	0.14	0.22	0.21	0.20	0.19	0.04
NA	0.26	0.28	0.27	0.26	0.22	0.32	0.30	0.28	0.26	0.21	0.34	0.26	0.29	0.03

15.3.2.5. Conclusions.

The hypotheses H^B_1 – H^B_5 (see Section 9) were aimed at testing the major assumptions underlying the proposed adaptation process of human behavior towards the environment and the influence of relevant variables reflecting individual differences between the actors on this adaptation process (see also Section 6.4 and 7.2).

When confronted with a totally unknown situation, an internal representation of this environment is built. Exploratory behavior and creative expressive actions take place in order to complement the sensory information. When the internal representation has been built, both decline. In order to test this assumption, the following operationalization has been chosen: The number of task-irrelevant operations for all four practice trials was calculated, i.e., the operations which do not directly contribute to achieving the relevant goal, but are crucial for complementing the visually available information. This number has been set in relation to the total number of operations executed. The inferential statistics applied demonstrate that the proportion of task-irrelevant operations decreases with increasing familiarity of the situation (see H^B_1). This decrease interacted significantly with the processing capacity and the verbal abilities of the study's participants: The participants with greater abilities required less exploratory activities and the proportion in question further decreased to a greater degree. It is assumed that the building the cognitive representation has been was quicker and required less information for the more able participants than for the less intelligent participants. In contrast to the relative number of task-irrelevant operations, however, the average duration of the task-irrelevant operations in relation to the average duration of all operations, does not change overall practice trials (see H^B_2). Hence, the difference in duration between a task-irrelevant operation and an average operation demonstrates that the acquisition of the information of interest does not differ between these classes of operations.

On a sound theoretical basis, it was further discussed that plans are worked out based on the built internal representation of the situation (see Sections 5.7 and 6.4). On the one hand, it was reasoned that, based on mental simulation, various ways of reaching the set goals are mentally simulated and the most promising one chosen. On the other hand, it was argued that also practical experience is needed to give valuable input. The latter has two effects: First, the average duration of operations is expected to decrease (see H^{B}_{3}), as better ways of achieving the results are found and second, different combinations of operations are tested (see H^{B}_{4}). The average duration of operations decreases, as does the different combinations of operations, which are tested. The effects differ, however, in their shape. While the average duration of the operations clearly decreases, the change of the number of strategic shifts performed follows an inverted “u”-shaped course: It increases initially but then decreases. Hence, testing different combinations of operations occurs at a later stage in the adaptation process, which concords with the theory: While the exploratory behavior takes place at the very beginning, testing different combinations of operations starts when the internal representation is at hand at least to a rudimentary degree. The feedback on these operations and their success does complement building the internal representation in an optimal degree. This reasoning holds as also the intelligence factors interact with both dependent measures (parallel with the hypotheses): Participants with greater processing capacities and verbal abilities have an advantage in the average duration of an operation, which increases with the number of practice trials performed. Hence, it is reasoned that the participants with greater intellectual abilities find a, for them better way to implement and realize the operations. The same is the case regarding the number of strategic changes performed: While the participants sample different strategies to achieve the goal, the participants with greater perceptual speed, verbal abilities or numerical abilities require a smaller number of strategic shifts to define a, for them optimal solution. It is of special importance that the number of strategic shifts follows an inverted “u”-shaped form for the participants with smaller intellectual abilities, but a linear course for the participants with greater measures. This supports the previously drawn conclusion that in a first step, an internal representation of the environment is built, which is only in a second step complemented with the feedback derived from the strategic changes performed. The change of the number of strategic changes also interacts significantly with the participants’ precision and velocity measures: The participants with greater velocity and precision measures show a smaller number of strategic changes in comparison with participants with smaller velocity and precision measures. An indirect effect was expected here: It is for the participants with smaller velocity and precision measures more important to success to define the best way to achieve the goal and complete the task.

After the internal representation of the environment has been built and complemented with feedback about the success of different realizations of the operations and strategies, the operations are grouped and no longer perceived as single operations. Instead, actions develop. In order to test this assumption, the number of actions has been counted which was expected to decrease with the familiarity of the situation (see H^B_5). This hypothesis has also been confirmed: The number of actions decreases. Hence, more and more operations are grouped and no longer perceived as single acts. However, an interaction effect with the cognitive abilities has not been found, probably due to the small sample size (see Section 15.2.2).

Summarizing, the hypotheses have mainly supported the assumptions about the proposed changes of human behavior in the course of an adaptation process to his/her environment and its interaction with the abilities such as intelligence and psychomotor abilities.

DISCUSSION AND FINAL REMARKS

16. Final Conclusions

The goal of this work was to acquire knowledge (1) about the way of how information in the environment is processed by an observer, (2) about the interaction between the processed information and the behavior of the observer, (3) about the role of the familiarity of the environment and (4) about the abilities determining the information acquisition and human behavior in environments, which novelty decreases. For this purpose, a theoretical basis was provided discussing a continuum of information acquisition starting from direct perception and ending with higher cognitive processes such as decision making and problem solving and a continuum of human behavior from exploratory, creative expressive behavior to direct activities, which no longer require information processing. Based on the proposed cognitive processes underlying these continui, abilities and characteristics of the situation have been determined which were expected to influence the adaptation process, which is reflected by moving from the one end of the continuum requiring a high level of information processing to the other end. A study was conducted to test major assumptions underlying these theoretical assumptions. These major assumptions have confirmed the theoretically discussed cognitive processes: As initially, when being confronted with a new situation, a cognitive or internal representation is built, which enables mentally simulating different courses to achieve the goal in question, the information processing demands are high. For this purpose, proximal variables are perceived, exploratory behavior executed. Both, the analyzed behavioral phenomena and the measured gaze behavior support the proposed cognitive processes. After having built this internal representation and after having tested different ways of achieving a goal, the information in the environment is specified which points to an action to achieve the goal in a given situation. The gaze durations on this anchor are prolonged. On the behavioral side of the adaptation process, it is characterized by a clustering of operations to actions. When the situation is familiar, behavior and eye movements are aligned: Anticipatory behavior decreases, operation-independent gazes occur to update the internal representation, and operation-relevant gazes are executed to get feedback on the progress of the currently undertaken operation.

The impact of the intelligence on that adaptation process has been demonstrated especially regarding the duration of the eye movements and the human behavior (i.e., average duration of operations); however, an influence on the actual course (e.g., the total number of gazes executed or the number of the task-related gazes) has not been revealed, except regarding the number of strategic changes performed. This number of strategic changes in human behavior is further influenced by the psychomotor abilities, which also determine the individual differences regarding the number and the duration of the operation-independent gazes. For all three effects, a theoretical, indirect effect has been proposed: It is for the participants with lower psychomotor abilities more important to determine the best solution of achieving the goal in comparison with the participants with greater ability levels. Further, the participants with greater psychomotor abilities have less time for executing (long) operation-independent gazes to update the internal representation, as they are expected to take place when the currently undertaken operation does no longer require the attention of the actor.

17. Limitations

These derived conclusions, however, have to be interpreted with caution: The external validity does not allow generalizing the derived results due to the small sample size and lacking representative design (Brunswik, 1943). Only the adaptation process to one new environment and one activity has been analyzed. This methodological approach taken, however, does assume univocality, which is not given in the real world. Instead, relationships in the environment do not hold with certainty. To gain situational generality, the environments and the tasks should have been randomized and a representative sample chosen. Problems are also at hand regarding the populational generality: Only wheelchair users have been included as participants in the study. Generalizing to the population of healthy individuals or other people with disabilities might be questioned. It is also to be considered that the sample size was quite small and only three types of disabilities were covered which caused the dependency on a wheelchair. The small sample size does also result in a low power of the study, so that some small effects, which might have actually been there in the real world, were not detected in the conducted study. Further limitations refer e.g., to the small number of tasks which were conducted by the participants, so that the participants could not reach the final level. However, due to the special needs of the sample, it was impossible to further prolong the duration of the study.

18. Contribution and Implications for the Field of Human-Technology Interaction

Despite the limitations of the study, the empirical results confirm the derived theoretical advancements and herewith complement existing research especially in the field of human-technology interaction. Previous research either focused on only aspect covering, for example, information acquisition (individual differences in relevant abilities and their impact were hardly ever considered in the field of human-technology interaction), or did not test the theoretical advancements in a sufficient basis, but only used the theories to derive guidelines, for example regarding interface design. Hence, the major contribution of this work is the comprehensive analysis of information acquisition and human behavior in the course of adaptation and the consideration of the influence of intelligence and psychomotor abilities on this adaptation process. Only a thorough and exhaustive understanding of these integrated processes in all components allows sound research on human-technology interaction, as it gives valuable insights in, for human-technology interaction relevant human behavior. Being aware of the expertise of the human user in a given situation and knowing the relevant structure of the environment allows predicting the stability of human behavior and herewith, human behavior itself. More specifically, statements on the amount and the level of human errors are possible, which yields the capacity to increase the dependability of complex computing systems, but it also allows predicting human behavior on an operational level. This is the case, as behavior on this level is stable, as long as relevant variables in the environment do not change. If such a change occurs and the operator is still an expert in the changed situation, predictive validity is remained. Routine operations are executed; reasoning about different ways of executing a task does not take place. Behavior is guided only by sensory-motor patterns. If ways of technically implementing such a comprehensive theory of human adaptation processes are developed, implemented and validated, this might significantly reduce the number of input commands required to control complex systems. Such a reduced number might make technical systems more usable by reducing the cognitive work load on the user. Summarizing, a valid technical implementation of such a comprehensive theory might enhance the dependability and/or the usability of technical systems.

Still, at that stage of research, important conclusions can be drawn regarding the intelligent wheelchair to be developed which should be directly controlled by natural gaze behavior:

- The familiarity of the environment the user is currently in must be taken into account, as the gaze behavior changes while adapting to a new situation.
- When interpreting especially the gaze durations, individual differences in intelligence and in psychomotor abilities of the users must be considered, as is the familiarity of the situation.
- When new in a situation, plans can give important insights into the future operations the person wants to execute. This advantage is, however, reduced the more familiar the situation is.
- In a totally familiar situation, most gazes are related to the current operation, especially for the participants with greater psychomotor abilities. Natural anticipatory gaze behavior is decreased, which highlights the importance to develop methods to realize the derived theoretical knowledge about human adaptation processes to predict future behavior based on relevant abilities, the degree of familiarity of the situation, the structure of the environment, and the proposed cognitive processes.

The impact which this research has, for example, on the usability of assisted wheelchair control especially for users with severe disabilities still has to be demonstrated. Future work will further has to confirm whether the implementation of such a comprehensive theory of the human user covering individual differences, information acquisition and behavior does have the proposed effects of enhancing the dependability of complex computing systems and their usability. For this purpose, a close cooperation between the involved disciplines of engineering and psychology is necessary.

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APPENDICES

Appendix A: Instructions for the Gardening Task

A.1 Original Version

Stellen Sie sich vor, Sie sind Gärtner und betreiben einen kleinen Laden, der verschiedene Pflanzen gemäß Kundenwünschen züchtet und verkauft. Hierfür säen Sie Samen und topfen die Jungpflanzen neu ein.

Der Raum, in dem wir uns gerade befinden, ist Ihre Gärtnerei. Hier finden Sie alles, was Sie benötigen:

- die Samen zur Aussaat
- die Blüten- und Grünpflanzen zum Eintopfen
- die Mittel zur optimalen Versorgung der Pflanzen, vor allem Düngemittel und Erde
- sowie weitere Hilfsmittel, die Sie bei der Erledigung Ihrer Aufgaben unterstützen.

Um ein optimales Ergebnis zu erzielen, müssen Sie je nach Kundenwunsch verschiedene Dinge beachten:

1.) Aussaat der Samen
Zur Aussaat benötigen Sie die vom Kunden gewünschten Pflanzensamen und eine geeignete Saatkiste. Diese Saatkiste müssen Sie mit Blumenerde füllen, die keimfrei ist und daher besonders geeignet zur Aufzucht von Pflanzen. Besonders wichtig ist, daß die Blumenerde sehr locker ist. Um dies zu gewährleisten, müssen Sie die Erde mit den Fingern zerbröseln und dann locker und gleichmäßig in der Pflanzenschale verteilen. Mit einem Holzstab müssen Sie dann Löcher in die Erde drücken und pro Loch einen Samen hineinsetzen. Samen können entweder Lichtkeimer oder Dunkelkeimer sein: Lichtkeimer werden nicht mit Blumenerde bedeckt, sondern mit feuchtem Zeitungspapier; Dunkelkeimer werden ein wenig mit Blumenerde bedeckt. Die die Dunkelkeimer bedeckende Erdschicht sollte maximal ca. 0,5 cm dick sein. Abschließend müssen die Samen gegossen werden. Das Wasser sollte möglichst 25°C haben. Außerdem muß das Wasser eventuell aufbereitet werden, sollte es zu sauer oder zu basisch sein. Um den Säuregehalt zu testen, wird ein entsprechender Teststreifen zur Bestimmung des Säuregehaltes 5 sec. in das Wasser gehalten. Der Säurewert bzw. pH-Wert kann durch Vergleichen der Verfärbung auf dem Teststreifen mit einer den Teststreifen beigefügten Farbskala abgelesen werden. Ist dieser Wert größer als 6, so muß dem Wasser etwas Essigsäure hinzugefügt werden, so daß das Wasser einen pH-Wert von 5 – 6 erreicht. Bei Werten unter 5 erhöht das Hinzufügen von basischen Mineralien den pH-Wert. Nach dem Gießen sollte die Erde leicht feucht sein.

2.) Eintopfen
Es ist notwendig, Pflanzen um- bzw. neu einzutopfen, wenn das Wurzelwerk der Pflanze zu groß für den ursprünglichen Topf geworden ist oder Nährstoffe in der Erde verbraucht worden sind. Der neue Topf sollte ca. zweimal so hoch sein wie das Wurzelwerk der Pflanze. Der Boden des Topfes wird dann zur Hälfte mit möglichst

lockerer Blumenerde gefüllt. Hierfür muß die Erde mit den Fingern zerbröselt und in den Topf gefüllt werden. Die Pflanze wird dann in den Topf gesetzt. Immer abwechselnd wird dann der Topf schichtweise mit dem passenden Dünger und Erde aufgefüllt. Nicht jeder Dünger ist geeignet für jede Pflanze:

- Grünpflanzen benötigen einen Dünger mit einem hohen Stickstoffgehalt.
- Blütenpflanzen benötigen einen Dünger mit einem hohen Phosphorgehalt.

Abschließend müssen die Pflanzen gegossen werden. Dieses Wasser sollte möglichst 25°C warm sein. Außerdem sollte das Wasser bzgl. des Säuregehalts untersucht werden und ein Säurewert von ca. 5-6 erreichen. Falls der Säurewert über 6 liegt, sollte genügend Essigsäure hinzugefügt werden; falls der pH-Wert unter 5 liegt, sollten etwas basische Mineralien dem Wasser hinzugefügt werden.

Haben Sie noch Fragen?

Während der Studie dürfen Sie jederzeit in diesen Unterlagen nachlesen.

Dann beginnen Sie bitte jetzt. Hier in diesem Kästchen finden Sie die Bestellungen Ihrer Kunden.

A.2 Translated Version

Imagine you are a gardener and run a little market, in which a variety of plants are grown and sold according to the requests of customers. For this purpose, seeds need to be sowed and seedlings need to be set in.

The room we are currently in is your garden market. Here, you will find everything you need:

- the seeds for sowing,
- the flowering and foliage seedlings to be set in, and
- the material required for the plants, especially soil and fertilizer, as well as
- further resources, which will help you to do a good job.

In order to achieve optimal results for each customer, you will have to consider various issues:

1.) Sowing seeds

For sowing, you need the - from the customer - requested seeds and an appropriate seed box. This seed box needs to be filled with soil, which is sterile and most convenient for breeding seedlings. It is especially important that the soil is very loose. To guarantee this, you have to crumble the soil with your fingers and spread the soil in a loose and evenly distributed way in the seed box. With a wooden stick, you then have to make holes into the soil and set one seed in each hole. The seeds are either light germinators or dark germinators. Light germinators need not to be covered with soil, but with wettish newspaper pieces; dark germinators need to be covered with soil. The layer of soil covering the dark germinators should be maximally about 0.5 cm thick. Finally, the seeds need to be watered. The water should be about 25°C warm. Further, the water might need to be prepared, if it is too acid or too alkaline. To test the acidity, a pH test strip needs to be hold into the water for about 5 seconds.

The acid value can be defined by comparing the discoloration of the pH test strip with a given color range. Is the acid value greater than six, acetic acid needs to be added to the water, so that its pH-value reaches a level between five and six. If it reached a value smaller than five, alkaline minerals need to be added to enhance the pH-value. After watering the seeds, the soil should be moistly.

2.) Setting in seedlings

When the roots of the seedlings are getting too big for their original pot or all nutriments in the soil are wasted, it is necessary to put the seedlings in bigger, more appropriate pots. This new pot should be about twice as high as the roots of the seedling. The bottom of the pot needs to be filled half with loosened soil. For this purpose, the soil must be crumbled with the fingers and filled into the pot. Then, the seedling will need to be set in the pot. In a next step, the pot needs to be filled with alternating layers of appropriate fertilizer and soil. Not every fertilizer can be used for the seedlings:

- Foliage plants require a nitrogenous fertilizer
- Flowering plants require a phosphoric fertilizer.

Finally, the plants need to be watered. The water should ideally be about 25°C warm. Further, the acidity of the water should be tested and its value should be between five and six. If the acidity value is greater than six, acetic acid should be added, if the acidity value is smaller than five, alkaline minerals should be added.

Do you have any questions?

During the study, you can glean these instructions at any time.

Please begin now. In this small box, you will find the customers' requests.

Appendix B: Customer Requirements

B.1 Original Version

1.) Frau Müller würde gerne im kommenden Sommer Sonnenblumen in ihrem Garten pflanzen. Die Sonnenblumen sind Dunkelkeimer. Frau Müller benötigt eine Saatkiste mit 5 Einzelschalen, so daß in jeder Einzelschale ein Samen gesät wird und eine Sonnenblume heranwachsen kann.

2.) Herr Mayer will die Blumenkästen seines Balkons neu bepflanzen. Hierfür müssen 3 Blütenpflanzen neu eingetopft werden.

3.) Herr Kiefer sucht 4 Grünpflanzen für seinen Garten, die neu eingetopft werden müssen.

4.) Frau Schneider mag Bärlauch sehr gerne. Für ihren Balkon hätte sie gerne eine Saatkiste mit 5 Einzeltöpfen. Pro Einzeltopf soll ein Samen gesät wird. Die Bärlauchsamen sind Lichtkeimer.

B.2 Translated Version

1.) Mrs. Müller would like to plant sunflowers in her garden during the next summer. Sunflower seeds are dark germinators. Mrs. Müller would like to have a seed box with 5 single pots, so that in each single pot one sunflower seed will be sown and one sunflower will grow.

2.) Mr. Mayer would like to replant the flower boxes of his balcony. For this purpose, he would like to have three flowering plants set in.

3.) Mr. Kiefer is looking for four foliage plants for his garden, which need to be set in.

4.) Mrs. Schneider likes ramson. For her balcony, she would like to have a seed box with five pots. In each pot, a ramson seed should be sown. The ramson seeds are light germinators.

Appendix C: Instructions for the "Motorische Leistungsserie"

C.1 Original Version

Der arbeitende Arm darf in keiner Weise aufgestützt werden (weder durch den Ellenbogen noch durch das Handgelenk); bei der Testdurchführung sollte die unbenutzte Hand locker neben der Arbeitsfläche liegen.

Instruktionen für die rechte Hand:

Steadiness
Es soll gemessen werden, wie ruhig Sie Ihre Hand in einer engen Begrenzung halten können. Sie sollen jetzt in die Mitte des zweitkleinsten Loches rechts in der unteren Reihe den Griffel bis zur Mitte der Spitze senkrecht hineinstecken. Halten Sie den Griffel dabei möglichst ruhig und genau senkrecht. Jede Berührung mit dem Rand und Boden wird als Fehler gezählt.

Linie Nachfahren
Im folgenden kommt es darauf an, daß Sie den Griffel präzise, ohne anzustoßen durch diese ausgestanzte Linie führen. Sie müssen dabei den Griffel senkrecht in der rechten Hand halten und vor allem darauf achten, daß Sie eine Berührung vermeiden. Dabei wird auch Ihre Geschwindigkeit gemessen, es kommt aber in erster Linie darauf an, daß Sie bei dieser Übung möglichst wenig Fehler machen. Sobald Sie den Griffel auf der Startplatte aufgesetzt haben, wird die Zeit gezählt. Der Startpunkt ist rechts. Fahren Sie dann ungefähr in dieser Tiefe weiter. Der Versuch endet, wenn Sie mit dem Griffel auf die linke Endplatte der Linie stoßen.

Aiming
Vor sich sehen Sie zwei Reihen goldener Kreise. Sie sollen jetzt jeden Kreis der oberen Reihe von rechts nach links möglichst genau einmal mit dem Griffel berühren. Sobald Sie daneben treffen, wird ein Fehler gezählt. Sie sollten den Griffel evtl. ein wenig schräg halten, damit Sie sich nicht mit der Hand die Sicht verdecken. Der Griffel sollte nicht allzu kräftig aufgeschlagen werden, die Berührung muß aber deutlich hörbar sein. Zielen Sie immer auf den Mittelpunkt, dann werden Sie sicherer treffen. Berühren Sie bitte zuerst den großen silbernen Kreis auf der rechten Seite, dann der Reihe nach die Kreise in der oberen Reihe und am Ende noch den großen, linken silbernen Kreis.

Tapping
Sie sehen vor sich eine quadratische Platte. Diese sollen Sie nun mit dem Griffel möglichst oft berühren, ohne zu erlahmen, also immer wieder auf die Platte schlagen, bis ich „Halt“ sage. Halten Sie den Griffel möglichst senkrecht und weit unten. Sie können bei diesem Versuch die Ellenbogen auf dem Tisch oder das Handgelenk auf der Arbeitsplatte aufstützen. Gezählt wird die Anzahl der Anschläge auf der Platte.

Instruktionen für die linke Hand:

Steadiness
Es soll gemessen werden, wie ruhig Sie Ihre Hand in einer engen Begrenzung halten können. Sie sollen jetzt in die Mitte des zweitkleinsten Loches links in der unteren Reihe den Griffel bis zur Mitte der Spitze senkrecht hineinstecken. Halten Sie den Griffel dabei möglichst ruhig und genau senkrecht. Jede Berührung mit dem Rand und Boden wird als Fehler gezählt.

Linie Nachfahren
Im folgenden kommt es darauf an, daß Sie den Griffel präzise, ohne anzustoßen durch diese ausgestanzte Linie führen. Sie müssen dabei den Griffel senkrecht in der linken Hand halten und vor allem darauf achten, daß Sie eine Berührung vermeiden. Dabei wird auch Ihre Geschwindigkeit gemessen, es kommt aber in erster Linie darauf an, daß Sie bei dieser Übung möglichst wenig Fehler machen. Sobald Sie den Griffel auf der Startplatte aufgesetzt haben, wird die Zeit gezählt. Der Startpunkt ist links. Fahren Sie dann ungefähr in dieser Tiefe weiter. Der Versuch endet, wenn Sie mit dem Griffel auf die rechte Endplatte der Linie stoßen.

Aiming
Vor sich sehen Sie zwei Reihen goldener Kreise. Sie sollen jetzt jeden Kreis der unteren Reihe von links nach rechts möglichst genau einmal mit dem Griffel berühren. Sobald Sie daneben treffen, wird ein Fehler gezählt. Sie sollten den Griffel evtl. ein wenig schräg halten, damit Sie sich nicht mit der Hand die Sicht verdecken. Der Griffel sollte nicht allzu kräftig aufgeschlagen werden, die Berührung muß aber deutlich hörbar sein. Zielen Sie immer auf den Mittelpunkt, dann werden Sie sicherer treffen. Berühren Sie bitte zuerst den großen silbernen Kreis auf der linken Seite, dann der Reihe nach die Kreise in der unteren Reihe und am Ende noch den großen, rechten silbernen Kreis.

Tapping
Sie sehen vor sich eine quadratische Platte. Diese sollen Sie nun mit dem Griffel möglichst oft berühren, ohne zu erlahmen, also immer wieder auf die Platte schlagen, bis ich „Halt“ sage. Halten Sie den Griffel möglichst senkrecht und weit unten. Sie können bei diesem Versuch die Ellenbogen auf dem Tisch oder das Handgelenk auf der Arbeitsplatte aufstützen. Gezählt wird die Anzahl der Anschläge auf der Platte.

C.2 Translated Version

It is not allowed to base the working arm (neither the elbow nor the wrist) on the chair or on the table; when executing the items, the hand not used should be placed in a casual way next to the work place.

Instructions for the right hand:

Steadiness
This item will measure how steady you can hold your hand within a narrow zone. For this purpose, you should place this stylus in the middle of the second smallest hole in the lower row of holes on the right side. The stylus should ideally be placed in an upright position and it should be put half inside the hole. You should try to keep it as calm as possible. Whenever you touch either rim or bottom of the whole, this will be counted as a mistake.

Line-tracing
In the following, it is required that you guide the stylus in a precise way, without touching the rim and/or bottom along this cut line. You have to hold the stylus in your right hand in an upright position and avoid touching the rim or the bottom of the line. The speed will also be measured; however, in first place, it is important that you make only a small number of mistakes. Whenever you touch the starting point with this stylus, the time recording will be started. Then, please follow the line in the same depth. You have to start from the right side. The recording stops, when you touch the end point at the left side of the line.

Aiming
In front of you, there are two lines with golden circles. You should touch each of the circles in the top line from the right to the left exactly once with this stylus. When you miss a circle, it will be counted as a mistake. You should consider holding the stylus in an imperfect upright position, as, otherwise, you might not have a good view on the circles. Further, do not hit the disc too hard, but touching the circle should be heard. Always aim at hitting the center of the circle in order to ensure that you hit it. Please start with the big circle in silver on the right side, then all golden circles in the top line and finish with the big silver circle on the left.

Tapping
There is a squared disc in front of you. With the stylus, you should touch this disc as often as possible, without getting slower. So, please hit that disc again and again, as long as I say “stop”. Try to hold the stylus in an upright position and at its lower end. For this test you are allowed to put elbow and wrist on the table. What is counted is the number of hits on the disc.

Instructions for the left hand:

Steadiness
This item will measure how steady you can hold your hand within a narrow zone. For this purpose, you should place this stylus in the middle of the second smallest hole in the lower row of holes on the left side. The stylus should ideally be placed in an upright position and it should be put half inside the hole. You should try to keep it as calm as possible. Whenever you touch either rim or bottom of the whole, this will be counted as a mistake.

Line-tracing
In the following, it is required that you guide the stylus in a precise way, without touching the rim and/or bottom along this cut line. You have to hold the stylus in your left hand in an upright position and avoid touching the rim or the bottom of the line. The speed will also be measured; however, in first place, it is important that you make only a small number of mistakes. Whenever you touch the starting point with this stylus, the time recording will be started. You have to start from the left side. Then, please follow the line in the same depth. The recording stops, when you touch the end point at the right side of the line.

Aiming
In front of you, there are two lines with golden circles. You should touch each of the circles in the top line from the left to the right exactly once with this stylus. When you miss a circle, it will be counted as a mistake. You should consider holding the stylus in an imperfect upright position, as, otherwise, you might not have a good view on the circles. Further, do not hit the disc too hard, but touching the circle should be heard. Always aim at hitting the center of the circle in order to ensure that you hit it. Please start with the big circle in silver on the left side, then all golden circles in the top line and finish with the big silver circle on the right.

Tapping
There is a disc in front of you. With the stylus, you should touch this disc as often as possible, without getting slower. So, please hit that disc again and again, as long as I say “stop”. Try to hold the stylus in an upright position and at its lower end. For this test you are allowed to put elbow and wrist on the table. What is counted is the number of hits on the disc.

Appendix D: Biographical Questionnaire

D.1 Original Version

Abschließender Fragebogen

Beantworten Sie bitte abschließend folgende Fragen zur Ihrer Person.

Die Daten werden selbstverständlich anonym behandelt. Um diese demographischen Daten mit den anderen erhobenen Werten in Verbindung setzen zu können, geben Sie bitte unten Ihren Fantasienamen an, den Sie auch bei der ersten Sitzung benutzt haben.

Fantasiename: ______________________

1.) Demographische Angaben

Alter	Jahre	
Geschlecht	☐ Männlich	☐ Weiblich
Händigkeit	☐ Rechtshändig	☐ Linkshändig

2.) Behinderung

Art der Behinderung	
Schwerbehindertenausweis	☐ Ja ☐ Nein ☐ Beantragt % und Merkmale (Buchstaben):
Pflegestufe	☐ Keine ☐ I ☐ II ☐ III ☐ beantragt

3.) Rollstuhl

Rollstuhl-Typ	☐ Elektrischer Rollstuhl ☐ Händischer Rollstuhl
Rollstuhl-Firma	
Modellbezeichnung des Rollstuhls	

4.) Schul- und Berufsausbildung

Letzter Schulabschluß der allgemein-bildenden Schule	
Momentane Berufsausbildung	☐ Berufsfindung ☐ Förderlehrgang ☐ Berufsschule
Berufsvorbereitung	☐ abgeschlossen ☐ noch nicht abgeschlossen
Berufsausbildung im	☐ Wirtschaft und Verwaltung

Bereich	☐ Metalltechnik ☐ Elektrotechnik ☐ Druck- und Mediengestaltung ☐ Ernährung und Hauswirtschaft ☐ Orthopädiemechaniker/Orthopädieschuhmacher ☐ noch nicht entschieden
Ausbildungsstand	☐ im 1. Jahr ☐ im 2. Jahr ☐ im 3. Jahr ☐ im 4. Jahr

5.) Erfahrung im Bereich Agrarwirtschaft/Landwirtschaft

Interesse für Agrarwirtschaft	☐ Agrarwirtschaft interessiert mich sehr. ☐ Agrarwirtschaft interessiert mich nicht so sehr. ☐ Agrarwirtschaft interessiert mich kaum. ☐ Agrarwirtschaft interessiert mich gar nicht.
Praktische Erfahrungen im agrar-wirtschaftlichen Bereich	☐ Ich habe sehr viel und sehr oft mit Pflanzen gearbeitet. ☐ Ich habe viel und oft mit Pflanzen gearbeitet. ☐ Ich habe ab und zu mit Pflanzen gearbeitet. ☐ Ich habe nie mit Pflanzen gearbeitet.

6.) Umgang mit dem Rollstuhl

Wie lange benutzen Sie schon einen Rollstuhl?	
Wie schwierig (d.h. zeitaufwendig) ist heute die Fahrt durch eine normal breite Tür?	☐ Sehr schwierig ☐ Schwierig ☐ Leicht ☐ Sehr leicht
Falls Sie nicht von klein an auf einen Rollstuhl angewiesen waren: Wie schwierig war die Fahrt durch eine normal breite Tür, als Sie das erste Mal im Rollstuhl saßen?	☐ Sehr schwierig ☐ Schwierig ☐ Leicht ☐ Sehr leicht
Wie schwierig (d.h. zeitaufwendig) ist heute die Fahrt um einen Tisch herum?	☐ Sehr schwierig ☐ Schwierig ☐ Leicht ☐ Sehr leicht
Falls Sie nicht von klein an auf einen Rollstuhl angewiesen waren: Wie schwierig war die Fahrt um einen Tisch herum als Sie das erste Mal im Rollstuhl saßen?	☐ Sehr schwierig ☐ Schwierig ☐ Leicht ☐ Sehr leicht
Was sind typische Probleme beim Umgang mit dem Rollstuhl im alltäglichen Leben?	1.) 2.)

	3.)

Vielen Dank für Ihre Teilnahme!

D.2 Translated Version

Final Questionnaire

Please answer the following questions.

The data will be recorded anonymously. In order to relate these data to the previously recorded data, please indicate your chosen fancy name, which you have also used in the first session of this study.

Fancy name: ______________________

1.) Demographic questions

Age	years	
Gender	☐ Male	☐ Female
Handedness	☐ Right handed	☐ Left handed

2.) Disability

Type of disability	
Severely handicapped pass	☐ Yes % and attributes (letters): ☐ No ☐ Applied for
Required nursing	☐ No ☐I ☐II ☐III ☐Applied for

3.) Wheelchair

Type of wheelchair	☐ Electrical wheelchair	☐Hand-driven wheelchair
Wheelchair company		
Wheelchair model		

4.) Education and vocational education

Last school leaving certificate from a general-education school	
Current stage of vocational education	☐ Finding appropriate profession ☐ Course for carrer advancement ☐ Vocational college
Vocational preparation	☐ Finished ☐ Not yet finished
Type of vocational education	☐ Economy and administration ☐ Metal engineering ☐ Electrical engineering ☐ Design of media and print ☐ Nutrition and home economics ☐ Orthopaedic shoemaker/mechanic ☐ Not yet decided
Year of vocational education	☐ In the 1st year ☐ In the 2nd year ☐ In the 3rd year ☐ In the 4th year

5.) Experience with agriculture

Interest in agriculture	☐ I am very interested in agriculture. ☐ I am quite interested in agriculture. ☐ I am hardly interested in agriculture. ☐ I am not at all interested in agriculture.
Practical experience with agriculture	☐ I have worked a lot with plants. ☐ I have worked with plants. ☐ I have worked with plants once in a while. ☐ I have never worked with plants.

6.) Usage of the wheelchair

How long do you use a wheelchair?	
How difficult (i.e., time-consuming) is it today to drive through a normal door?	☐ Very difficult ☐ Difficult ☐ Easy ☐ Very easy
If you have not used a wheelchair ab initio: How difficult was driving through a normal door when you were sitting in the wheelchair for the first time?	☐ Very difficult ☐ Difficult ☐ Easy ☐ Very easy
How difficult (i.e., time-consuming) is it today to drive around a table?	☐ Very difficult ☐ Difficult ☐ Easy

	☐ Very easy
If you have not used a wheelchair ab initio: How difficult was driving around a table when you were sitting in the wheelchair for the first time?	☐ Very difficult ☐ Difficult ☐ Easy ☐ Very easy
What are typical problems using a wheelchair in everyday life?	1.) 2.) 3.)

Thank you for your help and participation!

Appendix E: Detailed Description of the Operations

E.1 General Operations

Listening

Operation at the beginning of the study, when the instructions were read out by the experimenter and explained to the participant.

Picking up instructions

Movement of the hand to the instruction, touching it and preparing it for the next operation. This operation stops, as soon as the next operation is initiated.

Reading instructions

Reading the instructions, characterized by according eye movements over the piece of paper with the instructions.

Putting away instructions

Operation after e.g., reading instructions, when the piece of paper with the instructions is put back to its original location. The operation finishes when the hands no longer touch the paper and the next operation is initialized.

Picking up customer requirement

Movement of the hand to the customer requirement, touching it and preparing it for the next operation.

Reading customer requirement

Reading the customer requirement is characterized by according eye movements over the piece of paper with the requirements.

Break

Task-irrelevant operations are characterized as they do not demonstrate a required step for fulfilling the customer requests. Such task-irrelevant operations are for example conversations with the instructor, cleaning hands, etc. The break starts with the initiation of the task-irrelevant operation and stops as soon as a task-relevant operation is initialized.

Tidying up

“Tidying up” refers e.g., to putting away the sunflower seeds. These operations are not directly related to fulfilling the customer requests and are initiated when the hand moves towards the object which is tidied up. It stops when another operation is initialized, which is not related to tidying up any object.

E.2 Driving Operations

Routing

Movement of the wheelchair to be better able to perform the current operation required in order to fulfill the task requirements. This movement refers to better situating the wheelchair in relation to the table and necessary objects on the table.

Driving from customer table to work place

The operation starts when the participant starts moving the wheelchair and stops when the wheelchair does not move any more and a following operation is initialized.

Driving from work place to customer table

When the participant starts moving the wheelchair, the operation is initiated and is stopped, when the wheelchair does not move any more. The customer table is the one with the customer requirements.

Driving from work place to sunflowers

When the participant starts moving the wheelchair, the operation is initiated. The operation is stopped, when the wheelchair does not move any more and stands in front of the sunflowers at the bank.

Driving from sunflowers to work place

As with all driving operations, the operation is initiated, when the wheelchair starts moving and is stopped, when the wheelchair stops moving. The point of beginning is in front of the place, where the sunflowers are located on the bank; the end point is the work place at the work table.

Driving from work place to water table

Driving from work place to water table starts, when the participant starts moving the wheelchair and drives over to the water table. The operation stops as soon as the participant stops the moving wheelchair in front of the wheelchair.

Driving from water table to work place

Driving from the water table to the work place refers to the movement of the wheelchair, starting at the water table, ending at the work place.

Driving from work place to the resources

The place at the end of the bank where the resources are located, is the point, where this operation stops. It is the place at the bank, where e.g., the pH test strip and the thermometer are located. The movement starts when the participant starts moving the wheelchair at the work place.

Driving from the resources to work place

The operation is initiated when the participant starts moving at the bank, where the resources are located and stops, when the participant stops moving at the work place and initializes the next operation to be performed.

Driving from work place to salt

Salt is the place at the bank, where the salt is located. The operation starts when the wheelchair starts moving from the work place and stops when the participants reaches the salt and stops the wheelchair.

Driving from salt to work place

The operation "Driving from salt to work place" is initialized when the wheelchair user starts moving towards the work place and is stopped, when the wheelchair no longer moves and has reached the work place.

Driving from work place to phosphoric fertilizer

The participant initiates this operation when starting to move at the work place and stops this operation, when he/she reaches the place at the bank, where the phosphoric fertilizer is located and stops the wheelchair.

Driving from phosphoric fertilizer to work place

This operation starts when the participant starts moving the wheelchair at the place on the bank, where the phosphoric fertilizer is located and stops, when the participant reaches the work place and stops the wheelchair.

Driving from work place to nitrogenous fertilizer

The "Driving from work place to nitrogenous fertilizer" operation starts, when the participant starts moving the wheelchair at the work place and aims at reaching the place at the bank, where the nitrogenous fertilizer is located. The operation stops, when he/she successfully reaches this point and stops the wheelchair.

Driving from nitrogenous fertilizer to work place

This operation is characterized by the time period, during which the wheelchair moves from the place at the bank, where the nitrogenous fertilizer is located, to the work place.

Driving from customer table to light germinators

"Driving from customer table to light germinators" refers to the movement of the wheelchair between the customer table and the place at the bank, where the light germinators are located.

Driving from light germinators to work place

The operation is started, when the participant starts moving his/her wheelchair at the place at the bank, where the light germinators are located with the aim of reaching the work place. The operation is stopped, as soon as he/she does not move any more and has reached the work place.

Driving from work place to newspaper

The operation "Driving from work place to newspaper" is initialized, when the participant starts moving the wheelchair at the work place and drives over to the place at the bank, where the newspapers are located. The operation is stopped, when he/she stops moving the wheelchair and has reached the point of interest.

Driving from newspaper to work place

"Driving from newspaper to work place" is initialized when the participant starts moving the wheelchair at the place at the bank, where the newspaper is localized and moves in direction of the work place. It is stopped, when the user has reached the goal position and has stopped the wheelchair.

E.3 Operations Related to Filling the Pots

Picking up the scoop

"Picking up the scoop" starts with the movement of the hands towards the scoop and stops, as soon as the participant has grabbed it and initiated another operation (e.g., picking up soil).

Turning back the scoop

"Turning back the scoop" refers to moving the scoop from the pots in the seed box back to the soil, however, without putting it aside. The next operation to be initiated is performed with the scoop.

Putting away the scoop

In contrast to "Turning back the scoop", "Putting away the scoop" refers to moving the scoop from the seed box back to the soil box and putting it aside. The following operation is performed without the scoop.

Picking up soil

"Picking up soil" refers to moving the hand or the scoop towards the soil. The operation is stopped, after enough soil is in the hand of the participant or on the scoop.

Moving soil to Pot x

After picking up soil, the hand or scoop with the soil is moved to the pot in question, in which the soil is poured or crumbled in.

Pouring soil in Pot x

Pouring soil in a given pot refers to quickly putting the soil into the pot. The operation starts as soon as soil falls off the hand or from the scoop and it stops, as soon as no soil is left in the hand or on the scoop.

Crumbling soil in Pot x

"Crumbling soil in Pot x" refers to slowly putting the soil from the hands or the scoop into the pot so that loosening the soil in the pot is no longer required.

E.4 Operations Related to the Pots

Picking up empty pots

"Picking up empty pots" refers to the movement of the hand to the empty pots and picking up empty pots".

Picking up Pot x

"Picking up Pot x" is initiated when the hand is directed towards the pot of interest and the Pot x is picked up.

Situating Pot x

The operation "Situating Pot x" is performed, when the pot is placed on the seed box and adjusted in relation to the other pots'.

Counting pots

"Counting pots" refers to counting the number of pots in the seed box.

Straightening Pot x

Straightening Pot x refers to straightening the soil in the pot, so that it is distributed in a straight way.

E.5 Operations Related to the Seeds

Loosening soil in Pot x

The operation "Loosening soil in Pot x" refers to untightening the soil in Pot x with the fingers. The operation is initiated, when the hand starts moving towards the soil and is stopped, as soon as the soil is no longer touched.

Picking up the screwdriver

"Picking up screwdriver" refers to moving the hand towards the screwdriver and taking it into the hand.

Making hole in Pot x

This operation refers to making a hole for the seed in a given pot. This hole can either be made with the fingers or with the screwdriver. "Making the hole" starts as soon as the hand, the finger or the screwdriver touch the soil and stops, as soon as the hole has been made and the soil is no longer touched.

Picking up sunflowers

"Picking up the sunflowers" starts when the hand moves towards the package with the sunflower seeds. It stops, when this package has been picked up.

Opening sunflowers

"Opening sunflowers" refers to the operation related to opening the package with the sunflower seeds and to preparing the sunflower package to remove the seeds.

Putting sunflowers on table

This operation is characterized by pouring sunflower seeds on the table, from which they are - in another operation - picked up. The operation starts when turning the package and stops, when the seeds are on the table.

Picking up sunflower seed

This operation is initiated, as soon as the hand moves towards picking up the sunflower seed and stops as soon as the participant has managed to grab one of them.

Moving sunflower seed to Pot x

The movement from the location where the sunflower seed has been picked up to the pot, in which the seed will be sown, is referred to as "Moving sunflower seed to Pot x".

Putting sunflower seed in Pot x

The operation "Putting sunflower seed in Pot x" refers to sowing the sunflower seed into the hole that has been made into the soil in the pot. As soon as the seed is situated in the hole, the operation is stopped. The operation begins with the movement indicating that the seed will be put into this pot.

Covering Pot x

"Covering Pot x" is only required for sowing in dark germinators and refers to putting soil, which is already in the pot, into the hole, in which the seed has been put. This operation is initiated as soon as the participant's behavior aims towards moving soil from the side of the pot to put it into the existing hole. As soon as the soil is no longer touched, the operation is stopped.

Picking up light germinator

"Picking up light germinator" refers to the operation of moving the hand towards the bowl, in which the light germinators were placed and grabbing one light germinator. As soon as the participant holds a light germinator in his/her hand, the operation is stopped.

Moving light germinator to Pot x

Parallel to the proceeding with the sunflower seeds, after having picked up a light germinator, the movements of the hand with the light germinator to the pot, in which it will be sown, is referred to as "Moving light germinator to Pot x".

Putting light germinator in Pot x

The movement of the hand to sow the light germinator into the hole of the selected pot refers to this operation. The operation is initiated as soon as the hand indicates the sowing process. It is stopped as soon as the seed has been put into the hole in the soil.

E.6 Operations Related to Testing the Acidity of the Water

Tearing off pH strip

"Tearing off the pH strip" refers to moving the hand towards the strip, pulling it out and tearing it off. As soon as the participant has the strip in his hand, the operation is finished.

Picking up the pH test strip

"Picking up the pH test strip" refers to moving the hand towards the material to test the acidity of the water and to picking it up. After the pH test strip is in the hands of the participant, this operation stops.

Picking up the pH strip

"Picking up the pH strip" refers to moving the hand towards the ph strip, with which the acidity of the water can be tested. After the pH strip is in the hand of the participant, this operation is stopped.

Moving the pH strip to the water

The movement of the hand with the pH strip to the water is meant by this operation. The operation stops as soon as the pH strip touches the water.

Plunging the pH strip

"Plunging the pH strip" refers to the operation, during which the hand plunges the pH strip into the water and keeps it in the water.

Retrieving the pH strip

"Retrieving the pH strip" refers to pulling the pH strip out of the water. As soon as the pH strip is out of the water and dripping the water from the pH strip is finished, this operation is stopped.

Comparing with color chart

This operation refers to comparing the discoloration of the pH strip with the color chart. It contains observing the pH strip and moving the eyes back and forth from the color chart to the pH strip.

Putting away color chart

"Putting away color chart" refers to placing the color chart back on the table. This operation stops as soon as the hand no longer touches the color chart and starts with the movement of the hand to the table.

Picking up salt

The operation "Picking up salt" refers to moving the hands towards the salt and taking it into the hands; whereas the operation stops, as soon as the participant has the salt in his/her hands.

Putting salt in water

“Putting salt in water” refers to tilting the package containing the salt and pouring salt into the water. As soon as the salt is taken back into its original position, the operation stops.

Stirring up water

This operation starts when the participant stirs up the water, either with the fingers, the screwdriver or with the thermometer. The operation starts as soon as the fingers or the tool are put into the water and stops as soon as the fingers or the tool do no longer touch the water.

Picking up vinegar

“Picking up vinegar” refers to the hand’s movement towards the vinegar and picking it up. The operation stops as soon as the participant holds the vinegar in his/her hand.

Pouring vinegar in water

“Pouring vinegar in water” starts, when the bottle with the vinegar is tilted and the pouring of the vinegar into the water initiated. As soon as the vinegar is put into its original position, the operation is stopped.

E.7 Operations Related to the Thermometer

Picking up the thermometer

“Picking up the thermometer” refers to moving the hand towards the thermometer and picking it up. The operation stops as soon as the participant holds the thermometer in his/her hand.

Moving the thermometer to the water

The movement of the hand in the current position to the water in order to measure the water temperature is referred to as “Moving the thermometer to the water”.

Plunging the thermometer

“Plunging the thermometer” refers to putting the thermometer into the water and holding it there, so that the thermometer can adjust to the water temperature.

Retrieving the thermometer

“Retrieving the thermometer” refers to moving the thermometer out of the water. The operation stops when the thermometer is out of the water and the participant had let the rest of the water drip off.

E.8 Operations Related to Water

Picking up water

The movement towards a cup with water and taking it into the hand refers to "Picking up water". The movement stops as soon as the participant holds the water cup in his/her hand.

Moving water to Pot x

"Moving water to Pot x" is initiated when the water cup is moved from its current position towards the pot, in which water will be poured. As soon as the participant starts tilting the water cup, the operation is finished.

Pouring water in Pot x

"Pouring water in Pot x" is initiated as soon as the participant starts pouring the water into the pot and stops when the water cup is back in its original position.

Putting water in position

"Putting water in position" refers to the operation, in which the position of the water in the hand of the participant is changed in order to being better able to pour the water into the pot(s). An example is switching the water cup from the right to the left hand.

E.9 Operations Related to the Fertilizer

Picking up phosphoric/nitrogenous fertilizer

Moving the hand to the phosphoric/nitrogenous fertilizer and taking it into the participant's hand is referred to by this operation. It stops as soon as the phosphoric/nitrogenous fertilizer is in his/her hand.

Moving phosphoric/nitrogenous fertilizer to Pot x

The directed movement of the phosphoric/nitrogenous fertilizer to the pot, in which it will be put, is referred to as "Moving phosphoric/nitrogenous fertilizer to Pot x". The operation starts as soon as the fertilizer is moved directly to the pot and stops, when the cup containing the fertilizer is tilted towards the pot.

Putting phosphoric/nitrogenous fertilizer in Pot x

This operation refers to tilting the phosphoric/nitrogenous fertilizer in the direction of the pot and pouring the fertilizer into the pot. As soon as the phosphoric/nitrogenous fertilizer is back in its original position, the operation is stopped.

Putting phosphoric/nitrogenous fertilizer away

Tidying up the phosphoric/nitrogenous fertilizer after having used it refers to "Putting phosphoric/nitrogenous fertilizer away". The operation starts as soon as the cup containing the phosphoric/nitrogenous fertilizer is hold in an upright position and put on the table.

Distributing phosphoric/nitrogenous fertilizer in Pot x

"Distributing phosphoric/nitrogenous fertilizer in Pot x" refers to distributing the fertilizer poured into the pot all over the soil. The operation starts with the movement towards the fertilizer in the pot and stops when the soil/fertilizer is no longer touched.

E.10 Operations Related to the Plants

Picking up cup with flowering/foliage plants

This operation is initiated when the hand is moved towards the cup with the flowering/foliage plants. The operation stops as soon as the participant holds the cup in his/her hand.

Moving cup with flowering/foliage plants to seed box

"Moving cup with the flowering/foliage plants to seed box" refers to a directed movement of the cup with the flowering/foliage plants from its original position to the seed box, where the cup is put down.

Picking up flowering/foliage plants

The operation "Picking up flowering/foliage plants" refers to moving the hand to the flowering/foliage plants and pulling one out of the cup. As soon as the participant holds the flowering/foliage plant in his/her hand, the operation is finished.

Moving flowering/foliage plant to Pot x

The operation refers to the directed movement of the flowering/foliage plant to the pot, in which it will be planted. The participant already holds the plant in his hand and moves it to the pot.

Planting flowering/foliage plant in Pot x

"Planting flowering/foliage plant in Pot x" is initiated when the plant touches the soil the first time and is finished when the plant has been put into the soil.

E.11 Operations Related to the Newspaper

Picking up newspaper

The operation "Picking up newspaper" is moving the hand towards the newspaper and taking it into the hand. The operation stops as soon as the participant has grabbed it successfully.

Ripping of a piece

"Ripping of a piece" refers to the process of tearing off a piece from the newspaper. It starts with holding the newspaper, so that it can be torn off easily and ends when the participant has the piece in his/her hand.

Picking up a piece

The hand's movement to the piece and grabbing it refers to "Picking up a piece". The operation stops as soon as the participant holds the piece in his/her hand.

Dipping piece

"Dipping piece" refers to holding the piece of newspaper into the water and retrieving it. When the piece does no longer touch the water, the operation is finished.

Splitting a piece

The operation "Splitting a piece" refers to tearing apart a big piece of the newspaper. It starts, when the participant prepares the operation and holds the piece, so that it can be split easily and stops, when he/she has both pieces in his/her hand.

Moving the piece to Pot x

"Moving the piece to Pot x" is the directed movement of the piece to the pot, on which it will be placed. The piece is already in the hand of the participant, when the movement starts and stops as soon as the pot of interest is reached.

Putting piece on Pot x

The operation of placing the piece of newspaper on the pot refers to "Putting piece on Pot x".

Appendix F: Mapping of Operations and Objects

Operations	Associated object
General operations	
Listening	-
Picking up instructions	Instructions
Reading instructions	Instructions
Putting away instructions	Instructions
Picking up customer requirement	Customer requirement
Reading customer requirement	Customer requirement
Break	-
Tidying up	-
Driving operations	
Routing	Work place
Driving from customer table to work place	Work place, floor
Driving from work place to customer table	Customer table, customer requirement, floor
Driving from work place to sunflowers	Bank (sunflowers), floor
Driving from sunflowers to work place	Work place, floor
Driving from work place to water table	Water table, floor
Driving from water table to work place	Work place, floor
Driving from work place to the resources	Bank (resources), floor
Driving from the resources to work place	Work place, floor
Driving from work place to salt	Bank (salt), floor
Driving from salt to work place	Work place, floor
Driving from work place to phosphoric fertilizer	Bank (phosphoric fertilizer), floor
Driving from phosphoric fertilizer to work place	Work place, floor
Driving from work place to nitrogenous fertilizer	Bank (nitrogenous fertilizer), floor
Driving from nitrogenous fertilizer to work place	Work place, floor
Driving from customer table to light germinators	Bank (light germinators), floor
Driving from light germinators to work place	Work place, floor
Driving from work place to newspaper	Bank (newspaper), Floor
Driving from newspaper to work place	Work place, floor
Operations related to filling up the pots	
Picking up the scoop	Scoop
Turning back the scoop	Scoop, soil
Putting away the scoop	Scoop, soil
Picking up soil	Soil
Moving soil to Pot X	Pot X
Pouring soil in Pot X	Pot X
Crumbling soil in Pot X	Pot X

Operations related to the pots	
Picking up empty pots	Empty pots
Picking up Pot X	Pot X
Situating Pot X	Pot X
Counting pots	Pots
Straightening Pot X	Pot X
Operations related to the seeds	
Loosening soil in Pot X	Pot X
Picking up the screwdriver	Screwdriver
Making hole in Pot X	Pot X
Picking up sunflowers	Sunflowers
Opening sunflowers	Sunflowers
Putting sunflowers on table	Sunflowers
Picking up sunflower seed	Sunflower seed
Moving sunflower seed to Pot X	Pot X
Putting sunflower seed in Pot X	Pot X
Covering Pot X	Pot X
Picking up light germinators	Light germinators
Moving light germinator to Pot X	Pot X
Putting light germinator in Pot X	Pot X
Operations related to testing the acidity of the water	
Tearing off pH strip	pH strip
Picking up the pH test strip	pH test strip
Picking up the pH strip	pH strip
Moving the pH strip to the water	Water
Putting away color chart	Color chart
Plunging the pH strip	pH strip
Retrieving the pH strip	pH strip
Comparing with color chart	Color chart
Picking up salt	Salt
Putting salt in water	Water
Stirring up water	Water
Picking up vinegar	Vinegar
Pouring vinegar in water	Water
Operations related to the thermometer	
Picking up the thermometer	Thermometer
Moving the thermometer to the water	Water
Plunging the thermometer	Thermometer
Retrieving the thermometer	Thermometer
Operations related to water	
Picking up water	Water
Pouring water in Pot X	Pot X
Putting water in position	Water
Moving water to Pot X	Pot X
Operations related to fertilizer	
Picking up phosphoric/nitrogenous fertilizer	Phosphoric/nitrogenous fertilizer

Moving phosphoric/nitrogenous fertilizer to Pot X	Pot X
Putting phosphoric/nitrogenous fertilizer in Pot X	Pot X
Putting phosphoric/nitrogenous fertilizer away	Phosphoric/nitrogenous fertilizer
Distributing phosphoric/nitrogenous fertilizer in Pot X	Pot X
Operations related to plants	
Picking up cup with flowering/foliage plants	Flowering/foliage plants
Moving cup with flowering/foliage plants to seed box	Seed box
Picking up flowering/foliage plants	Flowering/foliage plants
Moving flowering/foliage plant to Pot X	Pot X
Planting flowering/foliage plant in Pot X	Pot X
Operations related to the newspaper	
Picking up newspaper	Newspaper
Ripping of a piece	Piece
Picking up a piece	Piece
Dipping piece	Piece, water
Splitting a piece	Piece
Moving the piece to Pot X	Pot X
Putting piece on Pot X	Pot X

Appendix G: List of Task-Irrelevant Objects

G.1 Task-Irrelevant Objects for the First Customer Requirement

Bank (light germinators)
Bank (newspaper)
Bank (nitrogenous fertilizer)
Bank (phosphoric fertilizer)
Bank (tissues)
Bank (vinegar)
Flowering plants
Foliage plants
Gloves
Instructions
Instructor
Room
Soil Box
Tissues
Towel
Vinegar
Water box

G.2 Task-Irrelevant Objects for the Second Customer Requirement

Bank (empty pots)
Bank (light germinators)
Bank (newspaper)
Bank (nitrogenous fertilizer)
Bank (sunflowers)
Bank (vinegar)
Hands
Instructions
Instructor
Nitrogenous fertilizer
Soil box
Sunflower seeds
Sunflowers

G.3 Task-Irrelevant Objects for the Third Customer Requirement

Bank (empty pots)
Bank (light germinators)
Bank (newspaper)
Bank (phosphoric fertilizer)
Bank (sunflowers)
Bank (towel)
Bank (vinegar)
Flowering plants

Hands
Instructions
Instructor
Phosphoric fertilizer
Soil box
Sunflowers
Water box

G.4 Task-Irrelevant Objects for the Fourth Customer Requirement

Bank (sunflowers)
Customer requirements
Customer table
Instructions
Instructor
Water box

Appendix H: List of Task-Irrelevant Operations

H.1 Task-Irrelevant Operations for the First Customer Requirement

Breaks
Counting pots
Listening
Putting away instructions
Putting salt in hand
Reading instructions
Removing soil
Routing
Situating empty pots
Straightening Pot X
Tidying up

H.2 Task-Irrelevant Operations for the Second Customer Requirement

Breaks
Picking up instructions
Putting away instructions
Putting salt in hand
Reading instructions
Routing
Situating flowering plants
Tidying up

H.3 Task-Irrelevant Operations for the Third Customer Requirement

Breaks
Counting pots
Driving from customer table to sunflowers
Driving from phosphoric fertilizer to workplace
Driving from sunflowers to customer table
Driving from workplace to phosphoric fertilizer
Putting salt in hand
Reading instructions
Routing
Situating foliage plants
Tidying up

H.4 Task-Irrelevant Operations for the Fourth Customer Requirement

Breaks
Counting pots
Covering pots
Reading instructions
Routing
Tidying up

Appendix I: List and Explanation of Possible Objects Gazes can be Directed at

Bank (light germinators)	Box of light germinators located on the bank
Bank (newspaper)	Newspapers located on the bank
Bank (nitrogenous fertilizer)	Pot with nitrogenous fertilizer located on the bank
Bank (pH test strip)	pH test strip located on the bank
Bank (phosphoric fertilizer)	Pot with phosphoric fertilizer located on the bank
Bank (resources)	Resources (thermometer, pencil sharpener, pencils, eraser, scissors) located on the bank (a better specification of the object the participant looked at was not possible, if the participants were not directly in front of these mentioned resources on the bank)
Bank (salt)	Salt located on the bank
Bank (screwdriver)	Screwdriver located on the bank
Bank (sunflowers)	Package with sunflowers located on the bank
Bank (thermometer)	Thermometer located on the bank
Bank (tissue)	Tissues located on the bank
Bank (towels)	Towels located on the bank
Bank (vinegar)	Vinegar located on the bank
Scoop	Scoop used e.g. to move soil from the soil box to a pot
Colour chart	Colour scale used to measure the discoloration of the pH strip
Cup with flowering plants	White cup, in which the flowering plants were put, on the work table
Cup with foliage plants	White cup, in which the foliage plants were put, on the work table
Customer requirement	Index card on which the customer request was printed
Customer requirements	Box with all index cards specifying all customer requests
Customer table	Table on which the box with all index cards with the customer requirements were located
Empty pot	One empty pot in the seed box
Empty pots	Stack of empty pots located in the seed box on the work table
Empty space	Empty space on the work table
Floor	Empty space on the floor
Flowering plants	Flowering plants located on the work table
Foliage plants	Foliage plants located on the work table
Gloves	Gloves located on the customer table
Hands/hand	Own hands (with or without gloves)
Instructions	Pieces of paper given the instructions for how to accomplish the gardening tasks

Instructor	Experimenter
Light germinator	Light germinator to be put in the pots
Light germinators	Box of light germinators located on the work table
Newspaper	Newspaper located on the work table
Nitrogenous fertilizer	Cup with nitrogenous fertilizer located on the work table
pH strip	pH strip removed from the complete pH test strip
pH test strip	pH strip and colour chart, i.e., complete equipment for measuring the acidity value
Phosphoric fertilizer	Cup with phosphoric fertilizer on the work table
Piece	Piece of newspaper
Pot 1	Pot located in the lower left corner of the seed box
Pot 2	Pot located in the middle of the lower row of pots in the seed box
Pot 3	Pot located on the lower right corner of the seed box
Pot 4	Pot located in the upper left corner of the seed box
Pot 5	Pot located in the upper right corner of the seed box
Room	Objects in the room not associated with the study
Salt	Salt located on the work table
Screwdriver	Screwdriver located on the work table
Seed box	Box in which the pots were located, on the work table
Soil	Soil used to fill the pots, located in the soil box on the work table
Soil box	Box in which the soil was, on the work table
Sunflower seed	Sunflowers seed to be put in the pots
Sunflowers	Package containing sunflower seeds
Thermometer	Equipment used to measure the temperature of the water
Tissue	Tissue which the participants could use to clean their hands
Towel	Towel with which the participants could dry their hands
Vinegar	Vinegar located on the work table, used to improve water quality
Water	Cup containing water
Water box	Box filled with water, this water was used to fill the water cups
Water table	Table on which the water box and the water cups were located
Work place	Place in front of the seed box
Work table	Table, on which the seed box, the soil box, and the plants were located

Appendix J: Correlations Between the Variables Involved in the Analyses Testing the Proposed Changes of the Human Gaze Behavior and its Interaction With the Variables Reflecting the Individual Differences

Table J1

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Total Number of Gazes and its Interaction With the Intelligence Factors (H^{I}_{1})

	1	2	3	4	5	6	7	8	9	10	11
1	-										
2	-.16	-									
3	-.23	.64**	-								
4	.07	.50*	.68**	-							
5	-.17	.87**	.89**	.65**	-						
6	.11	.68**	.75**	.85**	.81**	-					
7	-.24	.71**	.85**	.78**	.76**	.67**	-				
8	-.32	-.26	-.34	-.65*	-.28	-.51	-.49	-			
9	.43	-.70*	-.90**	-.74*	-.87**	-.84**	-.79**	.24	-		
10	-.04	-.22	-.70*	-.73*	-.51	-.80**	-.52	.46	.74*	-	
11	.22	-.49	-.54	-.45	-.45	-.61	-.55	.27	.54	.56	-

Note. 1 = CV1. 2 = K. 3 = B. 4 = M. 5 = V. 6 = N. 7 = F. 8 = NG-T1. 9 = NG-T2. 10 = NG-T3. 11 = NG-T4.

* $p < .05$. ** $p < .01$.

Table J2

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Average Duration of a Gaze and its Interaction With the Intelligence Factors (H^{I}_{2})

	1	2	3	4	5	6	7	8	9	10	11	12
1	-											
2	.12	-										
3	-.16	.24	-									
4	-.23	.64*	.64**	-								
5	.07	.47	.50*	.68**	-							
6	-.17	.39	.87**	.89**	.65**	-						
7	.11	.40	.68*	.75**	.85**	.81**	-					
8	-.24	.65*	.71**	.85**	.78**	.76**	.67**	-				
9	.34	-.31	-.73**	-.79**	-.41	-.87**	-.58	-.60	-			
10	.00	-.40	-.13*	-.66*	-.36	-.49	-.44	-.36	.53	-		
11	.42	-.04	-.36	-.54	-.42	-.49	-.39	-.50	.56	.73*	-	
12	.15	-.07	-.81**	-.51	-.59	-.73*	-.71*	-.54	.59	.27	.37	-

Note. 1 = CV1. 2 = CV2. 3 = K. 4 = B. 5 = M. 6 = V. 7 = N. 8 = F. 9 = DG-T1. 10 = DG-T2. 11 = DG-T3. 12 = DG-T4.

$^{*}p < .05$. $^{**}p < .01$.

Table J3

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Number of Task Related Gazes in Relation to the Total Number of Gazes and its Interaction With the Intelligence Factors ($H^I{}_3$)

	1	2	3	4	5	6	7	8	9	10	11
1	-										
2	-.16	-									
3	-.23	.64**	-								
4	.07	.50*	.68**	-							
5	-.17	.87**	.89**	.65**	-						
6	.11	.68**	.75**	.85**	.81**	-					
7	-.24	.71**	.85**	.78**	.76**	.67**	-				
8	.75*	-.10	.09	.12	.10	.10	-.06	-			
9	-.69*	.51	.07	-.31	.21	-.12	.15	-.36	-		
10	.40	-.01	-.22	-.06	-.07	-.19	-.12	.42	-.26	-	
11	.35	-.46	-.44	-.34	-.42	-.44	-.47	.06	-.48	.70*	-

Note. 1 = CV1. 2 = K. 3 = B. 4 = M. 5 = V. 6 = N. 7 = F. 8 = NRG-T1. 9 = NRG-T2. 10 = NRG-T3. 11 = NRG-T4.

* $p < .05$. ** $p < .01$.

Table J4

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Average Duration of Task Related Gazes in Relation to the Average Duration of all Gazes and its Interaction With the Intelligence Factors (H^I_4)

	1	2	3	4	5	6	7	8	9	10	11	12
1	-											
2	.14	-										
3	-.48	.10	-									
4	-.23	-.53	.15	-								
5	.32	.68*	-.13	-.12	-							
6	.54	.17	-.49	-.05	.12	-						
7	.04	-.48	-.11	-.17	-.16	.24	-					
8	.20	-.05	-.49	-.34	-.23	.64**	.64*	-				
9	.27	.34	-.09	-.74*	.07	.47	.50*	.68**	-			
10	.04	-.19	-.35	-.31	-.17	.39	.87*	.89**	.65**	-		
11	.44	.14	-.35	-.63*	.11	.40	.68**	.75**	.85**	.81**	-	
12	.14	-.12	-.14	-.38	-.24	.65**	.71**	.85**	.78**	.76**	.67**	-

Note. 1 = DRG-T1. 2 = DRG-T2. 3= DRG-T3. 4 = DRG-T4. 5 = CV1. 6 = CV2. 7 = K. 8 = B. 9 = M. 10 = V. 11 = N. 12 = F.

* $p < .05$. ** $p < .01$.

Table J5

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Number of Plans and its Interaction With the Intelligence Factors ($H^I{}_5$)

	1	2	3	4	5	6	7	8	9	10	11	12
1	-											
2	.12	-										
3	-.16	.24	-									
4	-.23	.64**	.64**	-								
5	.07	.47	.50*	.68**	-							
6	-.17	.39	.87**	.89**	.65**	-						
7	.11	.40	.68**	.75**	.85**	.81**	-					
8	-.24	.65**	.71**	.85**	.78**	.76**	.67**	-				
9	-.14	-.76*	-.17	-.65*	-.64*	-.41	-.57	-.60	-			
10	-.16	-.76*	-.16	-.50	-.18	-.34	-.30	-.32	.63*	-		
11	-.14	-.77**	-.32	-.69*	-.72*	-.52	-.68*	-.67*	.84**	.76*	-	
12	.00	-.74*	-.36	-.64*	-.39	-.50	-.46	-.54	.65*	.85**	.70**	-

Note. 1 = CV1. 2 = CV2. 3 = K. 4 = B. 5 = M. 6 = V. 7 = N. 8 = F. 9 = NPL-T1. 10 = NPL-T2. 11 = NPL-T3. 12 = NPL-T4.

* $p < .05$. ** $p < .01$.

Table J6

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Average Duration of a Plan and its Interaction With the Intelligence Factors ($H^I{}_6$)

	1	2	3	4	5	6	7	8	9	10	11	12
1	-											
2	.12	-										
3	-.16	.24	-									
4	-.23	.64**	.64**	-								
5	.07	.47	.50*	.68**	-							
6	-.17	.39	.87**	.89**	.65**	-						
7	.11	.40	.68**	.75**	.85**	.81**	-					
8	-.24	.65**	.71**	.85**	.78**	.76**	.67**	-				
9	.28	-.18	-.09	-.27	-.24	-.12	-.16	-.35	-			
10	-.04	-.49	-.20	-.49	.08	-.40	-.25	-.11	.30	-		
11	.20	-.52	-.54	-.70*	-.54	-.62	-.70**	-.60	.30	.42	-	
12	-.02	-.56	-.21	-.65*	-.30	-.51	-.25	-.48	.34	.63	.41	-

Note. 1 = CV1. 2 = CV2. 3 = K. 4 = B. 5 = M. 6 = V. 7 = N. 8 = F. 9 = DPL-T1. 10 = DPL-T2. 11 = DPL-T3. 12 = DPL-T4.

* $p < .05$. ** $p < .01$.

Table J7

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Average Difference of the Gazes on Anchors and on any Object and its Interaction With the Intelligence Factors ($H^I{}_7$)

	1	2	3	4	5	6	7	8	9	10
1	-									
2	$.64^{**}$	-								
3	$.50^{*}$	$.68^{**}$	-							
4	$.87^{**}$	$.89^{**}$	$.65^{**}$	-						
5	$.68^{**}$	$.75^{**}$	$.85^{**}$	$.81^{**}$	-					
6	$.71^{**}$	$.85^{**}$	$.78^{**}$	$.76^{**}$	$.67^{**}$	-				
7	-.50	-.52	-.11	-.53	-.32	-.39	-			
8	-.08	-.03	.24	-.18	-.08	.32	.46	-		
9	.63	.56	.42	.56	.45	$.66^{*}$	-.12	.17	-	
10	-.08	-.24	-.10	-.08	.17	-.46	.23	-.40	-.21	-

Note. 1 = K. 2 = B. 3 = M. 4 = V. 5 = N. 6 = F. 7 = DAG-T1. 8 = DAG-T2. 9 = DAG-T3. 10 = DAG-T4.

$^{*}p < .05$. $^{**}p < .01$.

Table J8

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Number of Operation-Independent Gazes in Relation to the Total Number of Gazes and its Interaction With the Psychomotor Factors (H^I_8)

	1	2	3	4	5	6	7	8	9
1	-								
2	.47	-							
3	.35	.53*	-						
4	.47	.57*	.87**	-					
5	.31	.54*	.68**	.82**	-				
6	-.52	-.34	.35	.20	.32	-			
7	-.59	-.60	.14	-.17	-.01	.81**	-		
8	-.57	-.50	-.34	-.54	-.36	.30	.53	-	
9	-.44	-.61	-.22	-.43	-.25	.28	.77**	.54	-

Note. 1 = CV2. 2 = ST. 3 = PR. 4 = VE. 5 = TP. 6 = NIG-T1. 7 = NIG-T2. 8 = NIG-T3. 9 = NIG-T4.
$^{*}p < .05$. $^{**}p < .01$.

Table J9

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Average Duration of Operation-Independent Gazes in Relation to the Average Duration of all Gazes and its Interaction With the Psychomotor Factors (H^{I}_{9})

	1	2	3	4	5	6	7	8	9
1	-								
2	-.30	-							
3	-.24	.53*	-						
4	-.35	.57*	.87**	-					
5	-.22	.54*	.68**	.82**	-				
6	-.04	-.35	-.77**	-.38	-.42	-			
7	-.11	.21	.09	.13	.15	.00	-		
8	-.15	.02	.21	.31	.13	.14	.78**	-	
9	.00	.49	.34	.27	.26	.04	.77**	.64*	-

Note. 1 = CV1. 2 = ST. 3 = PR. 4 = VE. 5 = TP. 6 = DIG-T1. 7 = DIG-T2. 8 = DIG-T3. 9 = DIG-T4.
$^{*}p < .05$. $^{**}p < .01$.

Table J10

Correlations Between the Variables Included in the Analyses Testing the Effect of the Object Relevance on the Gaze Duration (H^{I}_{10})

	1	2	3	4	5	6	7	8	9	10	11	12
1	-											
2	.53*	-										
3	.56*	.73**	-									
4	.59*	.27	.37	-								
5	.11	.36	.04	-.22	-							
6	.50	.66*	.63*	.51	-.01	-						
7	-.18	-.41	-.41	-.61*	.46	-.46	-					
8	-.26	.20	-.39	-.49	.24	-.07	.11	-				
9	.30	.42	.49	.21	.32	.11	-.38	-.27	-			
10	.44	.65*	.40	.26	.45	.72**	-.19	.17	-.07	-		
11	.76**	.28	.05	.28	.36	.32	.21	.16	-.05	.40	-	
12	.02	-.06	-.58	-.13	.29	-.36	.30	.71**	-.41	.09	.49	-

Note. 1 = average gaze duration in T1. 2 = average gaze duration in T2. 3 = average gaze duration in T3. 4 = average gaze duration in T4. 5 = OR-T1. 6 = OR-T2. 7 = OR-T3. 8 = OR-T4. 9 = DGO-T1. 10 = DGO-T2. 11 = DGO-T3. 12 = DGO-T4.

* $p < .05$. ** $p < .01$.

Table J11

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Difference Between the Start Dates of Gazes and Operations and its Interaction With the Intelligence Factors (H^{I}_{11})

	1	2	3	4	5	6	7	8	9	10	11
1	-										
2	-.16	-									
3	-.23	.64**	-								
4	.07	.50*	.68**	-							
5	-.17	.87**	.89**	.65**	-						
6	.11	.68**	.75**	.85**	.81**	-					
7	-.24	.71**	.85**	.78**	.76**	.67**	-				
8	-.20	-.36	-.43	-.45	-.50	-.36	-.41	-			
9	-.40	.38	.22	-.24	.34	.06	.02	.31	-		
10	-.26	-.08	-.10	-.42	-.20	-.30	-.10	.11	.07	-	
11	.06	-.53	-.32	-.58	-.49	-.35	-.56	.80**	.25	.30	-

Note. 1 = CV1. 2 = K. 3 = B. 4 = M. 5 = V. 6 = N. 7 = F. 8 = SDG-T1. 9 = SDG-T2. 10 = SDG-T3. 11 = SDG-T4.

* $p < .05$. ** $p < .01$.

Appendix K: Results of the Mauchly-Tests Testing the Sphericity Assumptions for the Hypotheses Analyzing the Human Gaze Behavior and its Interaction With the Measured Individual Differences

Table K1

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NG and its Interaction With the Intelligence Factors (H^{I}_{1})

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NGxK	0.61	3.28	5	.66	.82	1.00
NGxB	0.86	1.05	5	.96	.91	1.00
NGxM	0.79	1.62	5	.90	.87	1.00
NGxV	0.77	1.77	5	.88	.88	1.00
NGxN	0.83	1.29	5	.94	.90	1.00
NGxF	0.77	1.72	5	.89	.88	1.00

Table K2

Results of the Mauchly-Test Testing the Sphericity Assumption for the Single General Linear Model Analysis Performed to Test the Repeated Measurement Effect of NG

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NG	0.69	2.16	5	.83	.85	1.00

Table K3

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DG and its Interaction With the Intelligence Factors (H^I_2)

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
DGxK	0.83	0.87	5	.97	.89	1.00
DGxB	0.39	4.41	5	.50	.63	1.00
DGxM	0.40	4.39	5	.50	.61	1.00
DGxV	0.49	3.40	5	.65	.69	1.00
DGxN	0.46	3.72	5	.60	.65	1.00
DGxF	0.40	4.35	5	.51	.62	1.00

Table K4

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NRG and its Interaction With the Intelligence Factors (H^I_3)

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NRGxK	0.13	11.88	5	.04*	.46	.69
NRGxB	0.12	12.08	5	.04*	.46	.69
NRGxM	0.13	11.80	5	.04*	.45	.69
NRGxV	0.09	13.53	5	.02*	.44	.66
NRGxN	0.17	10.29	5	.07	.48	.74
NRGxF	0.14	11.34	5	.05	.46	.70

Note. * $p < .05$.

Table K5

Results of the Mauchly-Tests Testing the Sphericity Assumptions for Testing the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DRG and its Interaction With the Intelligence Factors ($H^I{}_4$)

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
DRGxK	0.02	18.90	5	$.00^{**}$	.44	.79
DRGxB	0.02	17.96	5	$.00^{**}$	.55	1.00
DRGxM	0.02	19.00	5	$.00^{**}$	.51	.33
DRGxV	0.02	17.59	5	$.00^{**}$	.53	1.00
DRGxN	0.05	14.26	5	$.02^{*}$	.63	1.00
DRGxF	0.01	21.89	5	$.00^{**}$	.43	.77

Note. * $p < .05$. ** $p < .01$.

Table K6

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NPL and its Interaction With the Intelligence Factors ($H^I{}_5$)

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NPLxK	0.40	4.30	5	.52	.69	1.00
NPLxB	0.40	4.40	5	.50	.69	1.00
NPLxM	0.32	5.32	5	.39	.68	1.00
NPLxV	0.39	4.40	5	.50	.68	1.00
NPLxN	0.30	5.70	5	.35	.67	1.00
NPLxF	0.38	4.55	5	.48	.68	1.00

Table K7

Results of the Mauchly-Test Testing the Sphericity Assumption for the Single General Linear Model Analysis Performed to Test the Repeated Measurement Effect of NPL

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NPL	0.42	4.98	5	.42	.70	1.00

Table K8

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DPL and its Interaction With the Intelligence Factors (H^I_6)

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
DPLxK	0.20	7.50	5	.19	.54	1.00
DPLxB	0.20	7.57	5	.19	.54	1.00
DPLxM	0.11	10.66	5	.06	.47	.33
DPLxV	0.21	7.41	5	.20	.54	1.00
DPLxN	0.15	9.02	5	.12	.47	.89
DPLxF	0.12	9.88	5	.09	.48	.91

Table K9

Results of the Mauchly-Test Testing the Sphericity Assumption for the Single General Linear Model Analysis Performed to Test the Repeated Measurement Effect of DPL

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
DPL	0.14	7.35	5	.21	.59	1.00

Table K10

Results of the Mauchly-Tests for Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DAG and its Interaction With the Intelligence Factors (H^I_7)

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
DAGxK	0.34	7.23	5	.21	.59	.84
DAGxB	0.38	6.50	5	.27	.63	.33
DAGxM	0.42	5.76	5	.33	.71	1.00
DAGxV	0.35	7.07	5	.22	.60	.86
DAGxN	0.38	6.45	5	.27	.65	.96
DAGxF	0.45	5.33	5	.38	.68	1.00

Table K11

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NIG and its Interaction With the Psychomotor Factors (H^{I}_{8})

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NIGxST	0.31	6.78	5	.24	.68	1.00
NIGxPR	0.29	7.06	5	.22	.72	1.00
NIGxVE	0.48	4.20	5	.53	.72	1.00
NIGxTP	0.43	4.90	5	.43	.76	1.00

Table K12

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DIG and its Interaction With the Psychomotor Factors (H^{I}_{9})

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
DIGxST	0.18	9.72	5	.09	.54	.87
DIGxPR	0.58	3.16	5	.68	.75	1.00
DIGxVE	0.26	7.70	5	.18	.58	.97
DIGxTP	0.33	0.36	5	.28	.61	1.00

Table K13

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of SDG and its Interaction With the Intelligence Factors (H^{I}_{11})

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
SDGxK	0.00	35.88	5	.00**	.35	.47
SDGxB	0.02	35.28	5	.00**	.35	.48
SDGxM	0.00	36.71	5	.00**	.35	.47
SDGxV	0.00	35.00	5	.00**	.35	.47
SDGxN	0.00	37.39	5	.00**	.35	.47
SDGxF	0.00	34.86	5	.00**	.35	.48

Note. ** $p < .01$.

Appendix L: Correlations Between the Variables Involved in the Analyses Testing the Proposed Changes of the Human Behavior and its Interaction With the Variables Reflecting the Individual Differences

Table L1

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Total Number of Task-Irrelevant Operations in Relation to the Total Number of Operations and its Interaction With the Intelligence Factors ($H^B{}_1$)

	1	2	3	4	5	6	7	8	9	10	11	12
1	-											
2	.64**	-										
3	.50*	.68**	-									
4	.87**	.89**	.65**	-								
5	.68**	.75**	.85**	.81**	-							
6	.71**	.85**	.78**	.76**	.67**	-						
7	-.16	-.23	.07	-.17	.11	-.24	-					
8	.24	.64**	.47	.39	.40	.65**	.12	-				
9	-.20	-.18	-.30	-.13	-.18	-.34	.13	-.22	-			
10	.13	-.28	-.15	-.06	.04	-.28	.05	-.35	.49	-		
11	.13	-.35	-.25	-.13	-.16	-.24	.20	-.19	.14	.79**	-	
12	-.30	-.47	-.26	-.30	-.32	-.49	-.10	-.73**	.46	.52	.21	-

Note. 1 = K. 2 = B. 3 = M. 4 = V. 5 = N. 6 = F. 7 = CV1. 8 = CV2. 9 = NIO-T1. 10 = NIO-T2. 11 = NIO-T3. 12 = NIO-T4.

* $p < .05$. ** $p < .01$.

Table L2

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Average Duration of the Task-Irrelevant Operations in Relation to the Average Duration of an Average Operation and its Interaction with the Intelligence Factors ($H^B{}_2$)

	1	2	3	4	5	6	7	8	9	10
1	-									
2	.64**	-								
3	.50*	.68**	-							
4	.87**	.89**	.65**	-						
5	.68**	.75**	.85**	.81**	-					
6	.71**	.85**	.78**	.76**	.67**	-				
7	.12	.30	.64	.17	.55	.40	-			
8	.00	.61*	.29	.36	.34	.34	.10	-		
9	.20	.54	.12	.43	.35	.24	.23	.52	-	
10	.06	.39	.01	.25	-.06	.29	-.06	.50	.49	-

Note. 1 = K, 2 = B, 3 = M, 4 = V, 5 = N, 6 = F, 7 = DIO-T1, 8 = DIO-T2, 9 = DIO-T3, 10 = DIO-T4.
* $p < .05$, ** $p < .01$.

Table L3

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Average Duration of an Operation and its Interaction With the Intelligence Factors (H^{B}_{3})

	1	2	3	4	5	6	7	8	9	10	11
1	-										
2	.64**	-									
3	.50*	.68**	-								
4	.87**	.87**	.66	-							
5	.69**	.75**	.85**	.81**	-						
6	.71**	.85**	.78**	.76**	.67**	-					
7	-.16	-.23	.07	-.17	.11	-.24	-				
8	-.35	-.62*	-.29	-.42	-.27	-.62*	.38	-			
9	-.28	.71**	-.41	-.46	-.44	-.60*	.23	.89**	-		
10	-.25	-.65*	-.53	-.41	-.51	-.61*	.32	.81**	.88**	-	
11	-.41	-.65*	-.56*	-.51	-.53	-.64	.10	.76**	.71**	.69**	-

Note. 1 = K. 2 = B. 3 = M. 4 = V. 5 = N. 6 = F. 7 = CV1. 8 = DO-T1. 9 = DO-T2. 10 = DO-T3. 11 = DO-T4.

* $p < .05$. ** $p < .01$.

Table L4

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Number of Strategic Changes and its Interaction with the Intelligence and the Psychomotor Factors ($H^B{}_4$)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-														
2	.64**	-													
3	.50*	.68**	-												
4	.87**	.89**	.65**	-											
5	.68**	.75**	.85**	.81**	-										
6	.71**	.85**	.78**	.76**	.67**	-									
7	-.16	-.23	.07	-.17	.11	-.24	-								
8	-.32	.01	.10	-.27	-.05	.10	.07	-							
9	-.41	-.51	-.41	-.61*	-.54	-.28	.15	.69**	-						
10	-.47	-.29	-.29	-.52	-.45	-.15	.07	.84**	.79**	-					
11	-.57*	-.15	-.10	-.42	-.36	-.10	.45	.75**	.63*	.74**	-				
12	.36	.57*	.27	.39	.24	.62*	-.30	-.11	-.34	-.32	-.16	-			
13	-.06	.35	.13	.17	.10	.20	-.24	-.21	-.48	-.48	.01	.53*	-		
14	.06	.56*	.20	.31	.24	.36	-.35	.17	-.28	-.19	.20	.57*	.87**	-	
15	.41	.62	.24	.56*	.43	.41	-.22	-.01	-.37	-.34	-.12	.54*	.68**	.82**	-

Note. 1 = K. 2 = B. 3 = M. 4 = V. 5 = N. 6 = F. 7 = CV1. 8 = NST-T1. 9 = NST -T2. 10 = NST -T3. 11 = NST-T4. 12 = ST. 13 = PR. 14 = VE. 15 = TP.

* $p < .05$. ** $p < .01$.

Table L5

Correlations Between the Variables Included in the Analyses Testing the Repeated Measurement Effect of the Number of Actions and its Interaction with the Intelligence Factors ($H^B{}_5$)

	1	2	3	4	5	6	7	8	9	10	11	12
1	-											
2	.12	-										
3	.12	-.23	-									
4	.24	-.18	.41	-								
5	.20	-.10	.50	.60*	-							
6	.30	-.40	.29	.28	.07	-						
7	-.16	.24	-.21	-.13	-.08	-.43	-					
8	-.23	.64**	-.13	-.53	-.34	-.35	.64**	-				
9	.07	.47	-.38	-.53	-.41	-.22	.50*	.68**	-			
10	-.17	.39	-.10	-.41	-.23	-.26	.87**	.89**	.65**	-		
11	.11	.40	-.10	-.35	-.19	-.21	.68**	.75**	.85**	.81**	-	
12	-.24	.65**	-.44	-.47	-.40	-.54	.71**	.85**	.78**	.76**	.67**	-

Note. 1 = CV1. 2 = CV2. 3 = NA-T1. 4 = NA-T2. 5 = NA-T3. 6 = NA-T4. 7 = K. 8 = B. 9 = M. 10 = V. 11 = N. 12 = F.

* $p < .05$. ** $p < .01$.

Appendix M: Results of the Mauchly-Tests Testing the Sphericity Assumptions Regarding the Analyses Performed for Testing the Change of the Human Behavior and its Interaction With Individual Differences

Table M1

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NIO and its Interaction With the Intelligence Factors (H^B_1)

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NIOxK	0.19	12.76	5	.03*	.60	.99
NIOxB	0.18	13.13	5	.02*	.60	1.00
NIOxM	0.15	14.48	5	.01*	.58	.94
NIOxV	0.18	13.14	5	.02*	.60	1.00
NIOxN	0.11	17.06	5	.01*	.59	.96
NIOxF	0.20	12.63	5	.03*	.60	1.00

Note. * $p < .05$.

Table M2

Results of the Mauchly-Test Testing the Sphericity Assumption for the Single General Linear Model Analysis Performed to Test the Repeated Measurement Effect of NIO

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NIO	0.19	12.92	5	.03*	.61	.93

Note. * $p < .05$.

Table M3

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of DIO and its Interaction With the Intelligence Factors ($H^B{}_2$)

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
DIOxK	0.67	4.00	5	.56	.83	1.00
DIOxB	0.69	3.61	5	.61	.84	1.00
DIOxM	0.71	3.30	5	.66	.85	1.00
DIOxV	0.69	3.61	5	.61	.84	1.00
DIOxN	0.07	3.96	5	.56	.81	1.00
DIOxF	0.66	3.98	5	.55	.83	1.00

Table M4

Results of the Mauchly-Test Testing the Sphericity Assumption for the Single General Linear Model Analysis Performed to Test the Repeated Measurement Effect of DIO

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
DIO	0.67	4.31	5	.51	.83	1.00

Table M5

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurements of DO and its Interaction With the Intelligence Factors ($H^B{}_3$)

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
DOxK	0.40	7.94	5	.16	.33	.72
DOxB	0.46	6.85	5	.23	.33	.70
DOxM	0.38	8.40	5	.14	.33	.62
DOxV	0.42	7.63	5	.18	.33	.70
DOxN	0.35	9.23	5	.10	.33	.61
DOxF	0.52	5.79	5	.33	.33	.74

Table M6

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NST and its Interaction With the Intelligence and Psychomotor Factors ($H^B{}_4$)

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NSTxK	0.59	4.52	5	.48	.77	1.00
NSTxB	0.81	1.87	5	.87	.90	1.00
NSTxM	0.66	3.67	5	.60	.83	1.00
NSTxV	0.73	2.72	5	.75	.85	1.00
NSTxN	0.40	8.06	5	.16	.74	1.00
NSTxF	0.72	2.91	5	.72	.85	1.00
NSTxST	0.71	3.04	5	.70	.83	1.00
NSTxPR	0.72	2.92	5	.72	.82	1.00
NSTxVE	0.77	2.23	5	.82	.88	1.00
NSTxTP	0.74	2.60	5	.76	.85	1.00

Table M7

Results of the Mauchly-Tests Testing the Sphericity Assumptions for the General Linear Model Analyses Performed to Test the Repeated Measurement Effect of NA and its Interaction With the Intelligence (H^{B}_{5})

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NAxK	0.70	2.81	5	.73	.82	1.00
NAxB	0.66	3.18	5	.68	.77	.33
NAxM	0.72	2.58	5	.77	.84	1.00
NAxV	0.70	2.78	5	.74	.82	1.00
NAxN	0.69	2.87	5	.72	.82	1.00
NAxF	0.70	2.72	5	.75	.83	1.00

Table M8

Results of the Mauchly-Test Testing the Sphericity Assumption for the Single General Linear Model Analysis Performed to Test the Repeated Measurement Effect of NA

Source	Mauchly-W	χ^2	*df*	*p*	G-G	H-F
NA	0.65	3.93	5	.64	.83	1.00

Erklärung

Hiermit erkläre ich, daß die vorliegende Arbeit von mir selbständig verfasst wurde und sämtliche, zur Bearbeitung des Themas herangezogenen Belege von mir deutlich gemacht und korrekt angegeben wurden.

Mannheim, den 16. Mai 2007 ……………………….