Institute of Exercise Training and Sport Informatics

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Head of Institute: Univ.-Prof. Dr. Daniel Memmert

**Ecological validity of cognitive-motor skills in everyday-like contexts: The role of distal goals**

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by

**Kyungwan Kim**

from

Seoul, Korea Republic

Cologne

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First reviewer: Univ.-Prof. Dr. med. Otmar Bock

Second reviewer: Jun.-Prof. Dr. Stefanie Klatt

Chair of the doctorate committee: Univ.-Prof. Dr. Mario Thevis

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Affidavits following §7 section 2 No. 4 and 5 of the doctoral regulations from the German Sport University Cologne, February 20th 2013:

Hereby I declare: The work presented in this thesis is the original work of the author except where acknowledged in the text. This material has not been submitted either in whole or in part for a degree at this or any other institution. Those parts or single sentences, which have been taken verbatim from other sources, are identified as citations.

I further declare that I complied with the actual “guidelines of qualified scientific work” of the German Sport University Cologne.

January 15, 2021

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**GENERAL COMMENTS**

The present work is a cumulative dissertation. It complies with the current doctoral regulations of the German Sport University Cologne and fulfills all conditions that are listed for a cumulative dissertation.

This dissertation consists of four studies that have been published or submitted in international peer-reviewed journals. The first and third studies have been published, whereas the second study is currently under major review. The last study has recently been submitted, to which I contributed as one of the co-authors.

The formatting of the articles differs in part from the published versions in order to maintain consistency within the dissertation (e.g. setting and numbering of tables or figures).

**LIST OF PUBLICATIONS**

**Study I**

Kim, K. & Bock, O. (2019). Ecological validity of manual grasping movements in an everyday-like grocery shopping task. *Experimental Brain Research*, *237*(5), 1169–1177. https://doi.org/10.1007/s00221-019-05496-0

(Impact factor of journal in 2019: 1.591)

**Study II**

Kim, K., Fricke, M. & Bock, O. (2020). Eye-head-trunk coordination while walking and turning in an everyday-like grocery shopping task. *Journal of Motor Behavior*, *31*, 1–8. https://doi.org/10.1080/00222895.2020.1811197

(Impact factor of journal in 2019: 1.279)

**Study III**

Kim, K. & Bock, O. (2020). Acquisition of landmark, route and survey knowledge in a wayfinding task: in stages or in parallel?. *Psychological Research*. https://doi.org/10.1007/s00426-020-01384-3

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**Study IV**

Mai, G., Kim, K., Klatt, S., & Bock, O. (2021). Does wayfinding practice modify the distribution of visuo-spatial attention?. *Psychological Research.*

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**SUMMARY**

To investigate individuals’ everyday life cognitive-motor skills, the degree of ecological validity to which laboratory experiments are representative and generalizable to situations outside the lab is an essential point. Despite the existence of a number of studies regarding ecological validity, there is a lack of clarity how to prove the extent of the ecological validity of the experiments intending naturalistic methods in studies of human cognitive-motor skills. Recently, it has been proposed that researchers investigating ecological validity of cognitive-motor skills should always specify and describe the specific functional context of the cognitive and behavioral processes one is interested in, by which the gap between typical laboratory and everyday life may be distinguished.

Given that cognitive-motor skills may be affected by participants’ attentional or motivational focus, this thesis deals with uncovering the role of distal goals as a specificity for ecologically valid experiments in cognitive-motor performance. Therefore, all experiments in this thesis required participants to focus on proximal goals while they attained distal goals, in order to induce responses and movements as natural as possible (e.g., finding and grasping objects, or body turns while wayfinding, or wayfinding while recognizing spatial features of surroundings).

First, the role of distal goals was determined depending on the way of the verification i.e., direct verification within an experiment (Study I), and indirect verification between previous and present experiments (Study II). Both studies were implemented in a simulated grocery shopping task. Study I verified whether the context dependence in grasping movements (laboratory vs. everyday-like context) holds the existing evidence even though a distal goal is embedded in the movement sequence. Study II analyzed the eye-head-trunk coordination while walking and turning with a distal goal to compare with results from literature.

Second, the role of distal goals was determined if distal goals lead to same or different learning curves in different experimental settings and task complexity. Contrary to Study I and II, Study III and IV implemented participants’ wayfinding ability in a virtually simulated urban city task (VR-City) with distal goals. VR-City required more complex tasks than grocery shopping task (more turns and to-be-recognized features), longer learning phase, as well as self-estimation after learning phase rather than simultaneous objective analysis.

Study I reaffirms and expands the existing evidence that the grasping movement is characterized differently in the laboratory and the everyday-like context, even though a distal goal was provided. Study II also demonstrated that the ordered sequence of eye- then head- then trunk turns can be observed not only with a proximal, but also with a distal goal. These results indicate that both direct and indirect verifications of ecological validity are conceivable when a distal goal is embedded in the movement sequence.

Furthermore, participants’ performance in Study III and IV showed gradually developed learning curves from the first to the last trials, whereas the performance in Study I and II showed striking change after the very first trial. These results confirms that the role of distal goals can be different depending on the experimental settings and task complexity.

Finally, this thesis suggests that distal goals are adequate as a particular specificity for ecologically valid experiments in cognitive-motor skills. Nevertheless, it remains questionable how to control the learning effect derived by repetitiveness of the tasks, even in employing naturalistic methods in an everyday-like context. As a matter of fact, repetitiveness of the experimental tasks is indispensable for collecting statistically comparable data. Thus, the challenge of future studies may be to develop a learning paradigm that is capable of producing robust implicit learning without concomitant explicit awareness.

**ZUSAMMENFASSUNG**

Um die kognitiv-motorischen Fähigkeiten des Alltags zu untersuchen, ist der Grad der ökologischen Validität, für den Laborexperimente repräsentativ und auf Situationen außerhalb des Labors verallgemeinerbar sind, ein wesentlicher Punkt. Trotz der Existenz einer Reihe von Studien zur ökologischen Validität besteht Unklarheit darüber, wie das Ausmaß der ökologischen Validität der Experimente zum Nachweis naturalistischer Methoden in Studien zur kognitiven und motorischen Kompetenz des Menschen nachgewiesen werden kann. Kürzlich wurde vorgeschlagen, dass Forscher, die die ökologische Validität kognitiv-motorischer Fähigkeiten untersuchen, immer den spezifischen funktionalen Kontext der kognitiven und Verhaltensprozesse spezifizieren und beschreiben sollten, an denen sie interessiert sind, anhand derer die Lücke zwischen typischem Labor und Alltag unterschieden werden kann.

Angesichts der Tatsache, dass kognitiv-motorische Fähigkeiten durch den Aufmerksamkeits- oder Motivationsfokus der Teilnehmer beeinflusst werden können, befasst sich diese Arbeit mit der Aufdeckung der Rolle distaler Ziele als Spezifität für ökologisch gültige Experimente zur kognitiv-motorischen Leistung. Daher mussten sich die Teilnehmer bei allen Experimenten in dieser Arbeit auf proximale Ziele konzentrieren, während sie distale Ziele erreichten, um so natürliche Reaktionen und Bewegungen wie möglich zu induzieren (z. B. Finden und Greifen von Objekten oder Körperdrehungen beim Wegfinden oder Wegfinden beim Erkennen von räumlichen Zielen Merkmale der Umgebung).

Zunächst wurde die Rolle distaler Ziele in Abhängigkeit von der Art der Verifizierung bestimmt, d.h. eine direkte Verifikation innerhalb eines Experiments (Studie I) und eine indirekte Verifikation zwischen früheren und aktuellen Experimenten (Studie II). Beide Studien wurden in einer simulierten Lebensmitteleinkaufsaufgabe durchgeführt. In Studie I wurde überprüft, ob die Kontextabhängigkeit beim Erfassen von Bewegungen (Labor- oder alltäglicher Kontext) die vorhandenen Beweise enthält, obwohl ein distales Ziel in den Bewegungsablauf eingebettet ist. In Studie II wurde die Koordination von Auge, Kopf und Rumpf beim Gehen und Drehen mit einem distalen Ziel analysiert, um sie mit den Ergebnissen aus der Literatur zu vergleichen.

Zweitens wurde die Rolle distaler Ziele bestimmt, wenn distale Ziele zu gleichen oder unterschiedlichen Lernkurven in unterschiedlichen experimentellen Umgebungen und Aufgabenkomplexitäten führen. Im Gegensatz zu Studie I und II implementierten Studie III und IV die Wegfindungsfähigkeit der Teilnehmer in einer virtuell simulierten Wegfindungsaufgabe (VR-City) mit distalen Zielen. VR-City erforderte komplexere Aufgaben als die Aufgabe des Lebensmitteleinkaufs (mehr Umdrehungen und zu erkennende Merkmale), eine längere Lernphase sowie eine Selbsteinschätzung nach der Lernphase anstelle einer gleichzeitigen objektiven Analyse.

Studie I bekräftigt und erweitert die vorhandenen Beweise dafür, dass die Greifbewegung im Labor und im alltäglichen Kontext unterschiedlich charakterisiert ist, obwohl ein distales Ziel vorgegeben wurde. Studie II zeigte auch, dass die geordnete Abfolge von Augen-, Kopf- und Rumpfumdrehungen nicht nur mit einem proximalen, sondern auch mit einem distalen Ziel beobachtet werden kann. Diese Ergebnisse zeigen, dass sowohl direkte als auch indirekte Überprüfungen der ökologischen Validität denkbar sind, wenn ein distales Ziel in den Bewegungsablauf eingebettet ist.

Darüber hinaus zeigte die Leistung der Teilnehmer in Studie III und IV allmählich entwickelte Lernkurven von der ersten bis zur letzten Studie, während die Leistung in Studie I und II nach der ersten Studie eine bemerkenswerte Veränderung zeigte. Diese Ergebnisse bestätigen, dass die Rolle distaler Ziele je nach experimentellen Einstellungen und Aufgabenkomplexität unterschiedlich sein kann.

Schließlich legt diese Arbeit nahe, dass distale Ziele als besondere Spezifität für ökologisch gültige Experimente mit kognitiv-motorischen Fähigkeiten angemessen sind. Es bleibt jedoch fraglich, wie der durch die Wiederholung der Aufgaben hervorgerufene Lerneffekt gesteuert werden kann, selbst wenn naturalistische Methoden in einem alltäglichen Kontext angewendet werden. Tatsächlich ist die Wiederholbarkeit der experimentellen Aufgaben für die Erfassung statistisch vergleichbarer Daten unabdingbar. Daher könnte die Herausforderung zukünftiger Studien darin bestehen, ein Lernparadigma zu entwickeln, das in der Lage ist, robustes implizites Lernen ohne begleitendes explizites Bewusstsein zu erzeugen.

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1. **SCIENTIFIC BACKGROUND**

Cognition is pivotal in psychology or sport psychology, however, there is a bewildering variety of different definitions and it remains unclear what cognition means and what it encompasses. Neisser (1967) defined the term cognition as the information processing that is used in diverse ways to transform, reduce, elaborate, store, and recover the sensory input. In other words, cognition is a form of mental processing that is enabling research into how people perceive, learn, remember, and think about information (Sternberg & Sternberg, 2011). It comprises many aspects of intellectual functions such as attention, memory, perception, judgment or problem solving etc. These factors are operated by contiguous causation like physical mechanisms such as the cogwheel, which is putting another cogwheel into motion (Houwer, Barnes-holmes, & Barnes-holmes, 2016).

On the other hands, motor skills can be defined as the ability which attained through learning. Motor skills allow to perform movements and actions with muscles (Stallings, 1973). In general, motor skills can be widely categorized into two groups: fine- and gross motor skills. Fine motor skills refer to the elaborate use of muscles for activities requiring the use of smaller muscle groups such as writing with a pencil, playing the piano, and grasping an object. Contrary to that, gross motor skills encompass movements or actions that require the use of larger muscle groups such as walking, running, jumping, or swimming.

Existing findings regarding the so-called dual task, have shown how closely cognition and motor skills are integrated with one another. Examples include conducting a visual search while walking and grasping a moving target while avoiding obstacles. The ability to administer dual tasks deteriorates with age (Beurskens & Bock, 2012; Bock, 2008) but can also be decremented at a young age due to increased visual task requirements (Krasovsky, Weiss, & Kizony, 2017). Indeed, our everyday life is impacted by numerous dual task situations. Therefore, examining integrated *‘cognitive-motor skills’* has become of high importance. The significant influence that dual task has on cognition and motor skills may additionally be explained e.g., by studies emphasizing the role of locomotion while wayfinding. The majority of studies on cognitive-motor skills was the use of typical laboratory settings e.g., using joysticks, keyboards, or questionnaires. Recently, research on cognitive-motor skills has taken a great leap forward by introducing virtual reality (VR) synchronized with a head-mounted display (HMD) and a non-motorized treadmill.

The integration of virtual reality is considered to be the best alternative for conventional settings because it enables the simulation of real-world surroundings (Diersch & Wolbers, 2019). In fact, investigating both internal (self-walk) and external (visual input) cues has benefits for gaining a better insight into the integration of cognition and motor skills. Nevertheless, there are several limitations accompanying such technologies, e.g., unfamiliar feelings or a constrained degree of movement differing from real-world situations, so that the extent of the ecological validity of ‘everyday-like’ studies has become the conversation topic.

* 1. **Ecological Validity**

Studies in terms of ‘real life’, ‘real world’, ‘everyday life’, or ‘everyday-like’ basically underlie the extent of the ecological validity of the experiments or the results. An ecologically valid experiment may provide logically sound data that represent individuals’ interaction with their surroundings. The concept of ecological validity has been defined as the extent to which results acquired in controlled laboratory experiments are associated with those obtained in real life situations (Chaytor & Schmitter-Edgecombe, 2003). Thus, to what extent an experiment produces ecological validity is an essential point when investigating individuals’ everyday life cognitive-motor skills. In other words, the degree to which laboratory experiments are representative and generalizable to situations outside the lab should be considered as relevant for the definition (Burgess et al., 2006).

Typically, the degree of ecological validity of an experiment can be identified by *verisimilitude* and *veridicality* (Chaytor & Schmitter-Edgecombe, 2003; Kenworthy, Yerys, Anthony, & Wallace, 2008). Verisimilitude refers to the extent of the relationship between the theoretical basis of an experiment and the cognitive demands of everyday life (Franzen & Wilhelm, 1996). In this approach, the establishment of an experiment should typically be considered from the beginning, while having ecological goals in mind (Wallisch, Little, Dean, & Dunn, 2018). For example, Study I and II of this thesis seem to meet the requirements of verisimilitude, since they were indeed established on considering ecological goals to attempt the simulation of critical everyday life tasks and to reaffirm previous findings which did not provide appropriate ecological validity due to typical laboratory features. This verisimilitude approach of increasing the ecological validity of the experiments has also resulted in the development of several standardized clinical tests that attempted to simulate everyday tasks that require cognitive functions such as attention, memory, and executive function (Chaytor & Schmitter-Edgecombe, 2003).

On the other hand, Study III and IV seem to relate to the veridicality referring to the degree of the empirical relationship between existing tests and measures of everyday functioning (Franzen & Wilhelm, 1996). The property of veridicality relates to experiments of value and predictive abilities of everyday function. Veridicality is typically known to relate to concurrent validity of two measures reflecting the same incidences of behavioral acts, but also refers solely to the extent of ecological validity (Portney & Watkins, 2009).

As an alternative, researchers have compared participants’ performances in both typical laboratory and everyday-like simulated contexts directly, based on the term ‘context dependence’ which means the discrepancy between both contexts. This context dependence has been established for grasping movements (Bock & Baak, 2013; Bock & Hagemann, 2010; Bock & Züll, 2013; Steinberg & Bock, 2013d), verbal memory performance (Godden & Baddeley, 1975), physiological state (Eich, 1980), and motor skills (Abrahamse & Verwey, 2008). Specifically, participants were required to reach different goals, but in equivalent environment. However, even though those studies have found significant differences between both contexts, there remained three intrinsic aspects that interrupt the trustworthiness of the context dependence.

First, subjects in both contexts were aware that they are participating in an experiment and that their movements are being recorded by equipment. They were also explicitly instructed about what exactly they have to do to reach a certain goal. In consequence, participants’ attentional and motivational focus on the attainment of the goal increased. Second, participants’ movements or performances in both contexts were executed for their own sake, whereas in everyday life, they are generally subordinated to a higher intention (Daprati & Sirigu, 2006; Henry & Rogers, 1960). For instance, we grasp a glass or a cup to drink water or coffee rather than only to grasp, or we walk and turn to reach a certain destination rather than only to walk and turn. Last but not least, participants’ movements in both contexts were externally triggered and were repetitive, whereas movements in everyday life are internally triggered by one’s own intentions (Palmer, Hiiemae, Matsuo, & Haishima, 2007; Waszak et al., 2005).

Nevertheless, there is a lack of clarity how to prove the extent of the ecological validity of the experiments intending naturalistic methods in studies of human cognitive-motor skills. Many researchers who pursue the real life approach assert that everyday-like experiments should achieve more ecological validity in order to generalize findings to the real life, instead of advocating how exactly we may interpret the extent of those studies’ ecological validity (Holleman, Hooge, Kemner, & Hessels, 2020; Schmuckler, 2001). Given the lack of classification, Schmuckler (2001) proposed three dimensions for evaluating a study’s ecological validity based on the nature of (1) the stimuli, (2) task, behavior or response, and (3) the experimental context. Then, several researchers have discussed this multidimensional framework with regard to artificiality vs. naturality, and simplicity vs. complexity of the conducted experiments (Hessels & Hooge, 2019; Kingstone, Smilek, & Eastwood, 2008; Risko & Kingstone, 2017; Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012; Sonkusare, Breakspear, & Guo, 2019). However, above contrast classification can also be suspicious in the persuasive judgment of how far the experiments intending everyday life cognitive-motor skills represent artificiality or naturality, and simplicity or complexity.

As another alternative to the blunt contrast classification mentioned above, Hammond (1998) and Holleman et al. (2020) proposed that researchers investigating ecological validity of cognitive and behavior studies should always specify and describe the particular reference frame by which the gap between typical laboratory and everyday life may be distinguished. Holleman et al. (2020) asserted some important aspects of the specification in terms of the ‘representativeness’ of the conducted experiments, and their ‘generalizability’ to the real life:

*“What is the specific functional context of the cognitive and behavioral processes one is interested in?”*, *“What are the relevant variables and conditions in this context given one’s focus of inquiry and level of analysis?”*, *“What do we know or assume to know about the range and distribution of these variables and conditions?”*,and *“How can these variables and conditions be represented in experimental designs to study specific patterns of cognitive and behavioral functioning?”* (Holleman et al., 2020, p. 9)*.*

Their argument regarding specification of a study’s representativeness is plausible, because it is in line with the original definition of ecological validity introduced as the ‘representative design’ of experiments which means a methodological guideline to achieve generalizable results (Brunswick, 1949, 1952). More specifically, Brunswick (1955, 1956) proposed to first specify the nature of the experiments by appropriate sampling representative subjects and experimental conditions such as stimuli, tasks, or situations, and then describe how those results can be represented and generalized in the experiments (Brunswick, 1956; Hammond & Stewart, 2001; Hogarth, 2005).

For the sake of a particular representativeness of ecologically valid studies, goal uncertainty may be a critical issue to represent more everyday-like cognitive-motor performance. Since our everyday life consists of dynamic and uncertain situations that are constantly changing, it is important to describe responses in the course of the perceptual process, movement planning, and movement execution when the ultimate goal of the task is unclear to participants. This goal uncertainty would occur when *proximal* and *distal* goals are given concurrently and it may affect participants’ cognitive-motor performance.

* 1. **Proximal and Distal Goals**

In everyday life, we usually focus elsewhere when reaching a proximal or distal goal, or when both goals concurrently followed, whereas typical laboratory experiments usually require only proximal goals. This fundamental discrepancy may result in different responses between everyday life and laboratory experiments, suggesting that cognitive-motor skills may be affected by participants’ attentional or motivational focus (Eversheim & Bock, 2002; Passingham, 1996).

Typically, movement planning to achieve a goal is supposed to comprise a serial order process: it begins with movement selection, followed by movement specification, and finally movement execution(Cisek, 2007). With respect to this process, recent neurophysiological studies proposed that movement selection and specification can also be planned concurrently (Cisek & Kalaska, 2010; Petzschner & Krüger, 2012) so that this concurrent process accounts for movement planning in the dynamic or uncertain situations (Cisek, 2007). This theory may be the key point for distinguishing between movement characteristics of typical laboratory and everyday-like contexts during the movement planning and execution process. Indeed, this assumption was not only theoretically confirmed (Cisek & Pastor-bernier, 2014) but also supported by empirical evidence (Gallivan & Chapman, 2014). The empirical findings have suggested that the concurrent movement planning does not only run until movement initiation but even after movement onset and during the course of movement execution.

As an example, with a particular focus on reaching movements, it has been sufficiently considered if the source of goal uncertainty has an effect on cognitive-motor performance, especially during the course of movement onset and execution. Nashed et al. (2017) challenged to attest to the existing assumption that individuals initially follow the average goal direction in the presence of goal uncertainty caused by multiple goals. They required participants to reach a single target (certain condition) or move towards two potential targets (uncertain condition) while grasping an object. They found the use of a single movement is optimizing motor costs more effectively than the average execution of movement. Furthermore, Krüger and Hermsdörfer (2019) compared reaching movements under three different conditions i.e., no uncertainty, extrinsic uncertainty and intrinsic uncertainty. They found that, compared to other conditions, extrinsic goal uncertainty results in an increase in the overall reaching movement duration. However, their experiments were conducted in typical laboratory settings and consisted of typical stimuli, therefore it remained unclear how movement planning and execution are characterized when faced with everyday-like goal uncertainty.

Typically, the terms proximal and distal goals have widely been used as short- and long-term goals that are achieved in a human lifetime. Depending on their involvement participants’ intrinsic motivation level enhances (Manderlink & Harackiewicz, 1984). Weldon and Yun (2000, p. 3) defined proximal goals as *“preliminary levels of performance to be achieved” and* distal goals as *“the ultimate level of performance to be achieved”*. In this thesis, the terms are used as the ‘core element’ that may distinguish between movements performed with different intentions and contexts. Thus, depending on which type of goals is being followed in the given behavioral sequence participants’ attentional focus and motivational level may be activated accordingly. Indeed, proximal goals are known to enhance self-efficacy (Stock & Cervone, 1990), intrinsic motivation (Morgan, 1985), and the persistence of participants (Bandura & Schunk, 1981). Thus, proximal goals are known to have a stronger influence to reach a better performance than distal goals. However, the enhancement of the components discussed, seem to represent a typical laboratory context. In other words, distal goals may represent an everyday-like context. Consequently, all of the experiments that will be introduced and discussed in this thesis required participants to focus on proximal goals while they attained distal goals, in order to induce responses and movements that were as authentic as possible (e.g., finding and grasping objects, or body turns while wayfinding, or wayfinding while recognizing spatial features of surroundings).

Several studies showed that human grasping is executed differently depending on physical properties, the context surrounding the object, and the ultimate (distal) goal of the grasping (Ansuini, Giosa, Turella, Altoè, & Castiello, 2008; Armbrüster & Spijkers, 2006; Naish, Reader, Houston-Price, Bremner, & Holmes, 2013). The presence of distal goals, in particular, is to provide subsequent actions that should be performed following grasping influences initial execution of movements (Ansuini et al., 2008). For example, in real life situations the goal of a grasping act is normally restricted to grasping an object, but subsequent ultimate goals are embedded in that grasping act such as to drink the water-filled in the grasped glass, or to give the object to someone. Moreover, other movements e.g., walk and turn, or wayfinding, may also be executed differently depending on the goal setting such as embedding subsequent actions or hiding unexpected acts in the sequence. Thus, it is conceivable that distal goals play an important role in discriminating between movement characteristics in a laboratory and everyday-like contexts. If so, the use of distal goals may result in the mediation of increasing participants’ motivation to perform the tasks.

In the literature, two components of motivation, i.e., expectancy and autonomy of the movement performer, are thought to optimize motor learning and performance (Lewthwaite & Wulf, 2017). According to the OPTIMAL theory of Wulf and Lewthwaite (2016), participants’ autonomy is a particularly important component for the optimization of performance. When participants are being given autonomy, the motivational underpinnings of motor learning and performance benefits are enhanced (Lemos, Wulf, Lewthwaite, & Chiviacowsky, 2017). Researchers have identified those benefits as autonomy support. Practice conditions that provide participants with autonomy support have exhibited higher effectiveness on motor learning and performance compared to conditions without the autonomy support (Lewthwaite & Wulf, 2012; Sanli, Patterson, Bray, & Lee, 2013). However, the effects of autonomy can vary since they depend on the individual and the type of task.

* 1. **Cognitive-Motor Skills in Everyday Life**

For the sake of the specifying the ecological validity of cognitive-motor skills, this thesis aims to determine the role of proximal and distal goals while performing cognitive-motor skills in everyday life situations. Thus, the following skills that we usually use every day have been examined: *grasping* (Study I), *body turns* (Study II),and *wayfinding* (Study III & IV).

* + 1. ***Grasping***

Grasping is a common daily activity and one of the important component of the fine motor skills. Along with the other motor skills, grasping plays a key role in interacting with today’s highly-developed society. For example, we are often facing a constant change in movement between grasping various objects in everyday life, such as a smartphone, a computer mouse, a wallet, books, or glasses. We spend half of our day grasping and manipulating objects and occasionally we even make mistakes. Fundamental damage can occur when such mistakes are made. For example, if we are dropping our smartphone or a glass filled with water. The risk of causing damage rises with advancing age due to increasing instability of the ability to grasp (Bock & Steinberg, 2012; Ketcham, Seidler, Gemmert, & Stelmach, 2002).

Grasping is a visually guided prehension for which the location and features of the to-be grasped object should be identified by eye-hand coordination (Shadmehr & Wise, 2005). Theoretically, grasping consists of two components which reflect distinct kinematic features and different neural substrates: a *transport* component which brings the hand into the vicinity of the object of interest, and a *grasp* component in which fingers are shaped in accordance with the features of the object (Dubrowski, Bock, Carnahan, & Jüngling, 2002; Jeannerod, 1984). As soon as the finger contacts the object, it applies grip and load forces to it in a well-coordinated way. There remains a small safety margin of the grip force over the load force (Johansson & Westling, 1984). Even though the integration of grip and load forces is extremely automatized, it is flexible enough to allow any corrections based on sensory feedback (Hermsdörfer et al., 2000), and to compensate massive changes in the gravito-internal environment (Rand, Shimansky, Stelmach, & Bloedel, 2004). Among multiple subcomponents of grasping, grip selection is essentially affected by the object’s visual and tactile properties. For example, compared to light or rough objects, a more accurate and larger grip is required when objects are heavy or slippery (Smeets & Brenner, 1999).

The organization and control of human movements are indeed functionally dependent on the context (Arbib, 1985). This context-dependence was also demonstrated by a number of grasping studies (Baak & Bock, 2015; Bock & Hagemann, 2010; Bock & Züll, 2013; Steinberg & Bock, 2013b, 2013d). Those studies established that context-dependence in grasping movements is attributable to multiple components such as cognitive functions, aging, or handedness. This corresponds well to the findings of the existence of two occipito-frontal cortical pathways: a *dorsal* and a *ventral* pathway that are divergent in their use of visual information (Ungerleider & Mishkin, 1982; Young, 1992). The ventral pathway is known as “what pathway and vision for perception” and represents the visual information processing in object identification and recognition. The dorsal pathway is known as the “where pathway and vision for action” and processes visual information relative to the viewer and intervenes with goal-directed motor actions (Goodale & Milner, 1992). The ventral pathway is involved in slow and attention-demanding behavior represented mainly in an everyday-like context, while the dorsal pathway is engaged in quick automated responses represented mainly in a laboratory context (Daprati & Sirigu, 2006).

* + 1. ***Body Turns***

In everyday life situations, we do not only constantly make small gaze shifts using the eye and head only, but we also make large gaze shifts using trunk and foot rotations (Land, 2004). Thus, researchers have emphasized the role of whole body turns while standing or while performing straight and circular locomotion. Making appropriate body turns can be guaranteed by using vestibular information providing the stability of the visual scene. For instance, patients with bilateral vestibular loss that is usually occurred by movement-related oscillation or visual blurring are displaying impaired physical functioning and a worse quality of life (Grunfeld, Morland, Bronstein, & Gresty, 2000), as well as an increased risk of falls (Schniepp et al., 2017).

Researchers found that we direct our gaze and head toward the side of the trajectory concavity (Grasso, Glasauer, Takei, & Berthoz, 1996), or toward the inner side of the road bend when driving a car (Land & Lee, 1994). This anticipatory strategy is a fundamental part of our everyday life activities, and it allows us to maintain dynamic stability during goal-directed locomotion (Patla, Adkin, & Ballard, 1999). In contrast to other anticipatory adaptive strategies, in gait research step length and step width regulation are planned during a step cycle and steering control to change the direction is planned and initiated in the step before (Patla, Prentice, Robinson, & Neufeld, 1991). When the ongoing locomotion was not yet terminated, the control of the body reorientation, which is embedded in other structural adjustments of the ongoing step cycle, is required (Patla et al., 1999).

Especially, the anticipatory steering control of locomotion has typically been known to be initiated by a horizontal reorientation of the eyes and head, followed by the trunk (Grasso, Prevost, Ivanenko, & Berthoz, 1998; Hollands, Patla, & Vickers, 2002; Hollands, Ziavra, & Bonstein, 2004; Imai, Moore, & Raphan, 2001; Lamontagne & Fung, 2009). This ordered sequence is a complex process involving anticipatory oriented behavior for maintaining stabilization and for establishing a stable frame of reference for future sensorimotor events associated with the control of body reorientation (Lamontagne & Fung, 2009). It has been widely known that the ability to control complex locomotion such as changing the direction while walking, is diminished in individuals with age-related (Paquette, Paquet, & Fung, 2006; Paquette & Vallis, 2010) and neurodegenerative diseases such as a stroke (Lamontagne & Fung, 2009) or Parkinson’s disease (Ambati, Saucedo, Murray, Powell, & Reed-Jones, 2016; Huxham, Baker, Morris, & Iansek, 2008). Moreover, it is also diminished in children with cerebral palsy (Bartonek et al., 2018). Individuals with the above-mentioned conditions display an ‘en-bloc’ movement of the eyes, head and trunk when they change the direction while walking, rather than showing a sequenced order which normally characterizes healthy individuals: the eyes turn first, followed by the head, and finally the trunk.

* + 1. ***Wayfinding***

Wayfinding is a requisite requirement of everyday life, and it comprises the almost cognitive-motor skills such as perception, spatial memory, visual attention, and/or locomotion. Researchers in wayfinding ability have proposed that we differ in our ability to perceive spatial attributes based on two main representations of space: egocentric (self-to-object relationships) and allocentric (object-to-object relationships) reference frames (Norman, Crabtree, Clayton, & Norman, 2005). The egocentric reference frame relies on a first-person perspective and is based on local landmarks which are perceived along the way (Wolbers & Hegarty, 2010). The allocentric reference frame refers to a bird’s eye perspective and is often called the ‘cognitive map’. It enables us to picture direct paths or shortcuts between unseen goal locations (Burgess, Spiers, & Paleologou, 2004). We can show preferences for one of both reference frames, or for switching between them. This reference frame choice can depend on multiple factors such as gender (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006), age (Fricke & Bock, 2018), hormonal fluctuations (Korol, Malin, Borden, Busby, & Couper-Leo, 2004), demands of different navigation tasks or available information, and the reliability of available cues (Etchamendy & Bohbot, 2007; Foo, Warren, Duchon, & Tarr, 2005).

Based on those individually different reference frames of space, we acquire spatial knowledge about the environment. There are cognitive mechanisms underlying spatial knowledge development and we should know how we can use the knowledge on the functioning of these processes to improve our spatial orientation. In order to effectively develop such knowledge, we need to be able to perceive specific spatial features in the environment, such as characteristics of salient landmarks, distance and direction between landmarks, and the connectivity across routes (Wolbers & Hegarty, 2010). In addition, the spatial knowledge develops with more exposures to specific locations or routes (Tommy Gärling, Böök, Lindberg, & Nilsson, 1981; Siegel & White, 1975; Thorndyke & Goldin, 1981).

Using spatial knowledge during wayfinding is typically classified into three general types: landmark, route, and survey knowledge (Siegel & White, 1975). First, *landmark knowledge* refers to the identities of discrete objects or scenes which are salient and used for location identification such as skyscrapers, stores, or public transit stations. Most critically, landmarks do not contain expressive spatial information themselves, but rather the local spatial information implied by salient patterns (Montello, 1998). The second element, *route knowledge*, represents the sequence of landmarks and associated intersections linked by experienced paths of movement (e.g., “turn right at the supermarket and go straight for two blocks”). Typically, route knowledge is described as accumulated knowledge obtained through drawing on past experience, rather than initially based on information about metric knowledge such as distances and directions (Montello, 1998; Siegel & White, 1975). *Survey knowledge*, the final element of the framework, is a “map-like” representation and said to derive from accumulated route knowledge. It is known as a quantitatively scaled representation of the layout of the environment and represents metric relationships among landmarks and routes, including straight-line distances and directions between which direct travel has never occurred (Hegarty et al., 2006).

1. **RESEARCH QUESTIONS**

As described in 1.1, whether a laboratory study has appropriate ecological validity should be verified by specifying and describing the particular reference frame by which the experimental settings and those obtained results may be generalizable to the real life (Hammond, 1998; Holleman et al., 2020; Schmuckler, 2001). The experiments of this thesis were carried out in two everyday-like approaches: a grocery shopping task (Study I & II) and a VR-City task (Study III & IV). Even though both approaches were designed as natural as possible (e.g., walking through natural or everyday-like visual stimuli), whether they are represented to the real life remained unclear, because they indeed were set up in the isolated laboratory containing typical experimental surroundings.

To minimize the intrinsic attribute of the laboratory experiments, participants were implicitly instructed so that they did not know what exactly the ultimate goal of the experiments. As such, they were not aware of the existence of distal goals and recognized it very naturally by accumulated exposures across all experiments. Thus, embedding a distal goal in the complex behavioral sequence of gait initiation, path planning, locomotion, change of heading, and wayfinding was the particular context-specific and context-generic principle of this thesis’s cognition and movement. Based on the assumption of Hammond (1998), Holleman et al. (2020), and Schmuckler (2001) that researchers should clearly specify and describe the particular reference frame for the ecological validity of the context, it is necessary to specifically interpret to what extent the experiments of this thesis and their results are ecologically valid with regard to the verisimilitude and veridicality attributes, and how they are representable and generalizable to our real life cognitive-motor skills and performance.

Therefore, this thesis deals with uncovering the effects of distal goals on various everyday life cognitive-motor skills in order to argue the role of distal goals as the adequate representativeness for ecologically valid experiments. The role of distal goals will be verified by two different aspects as followed: in different contexts and different experimental settings. All studies of this thesis were therefore implemented by providing a concurrence of proximal and distal goals through everyday-like experimental settings and implicit instructions, and also by increasing task complexity compared to previous studies.

* 1. **First research question**

“The role of distal goals in different ways of verification”

First research question of this thesis is to determine the role of distal goals as a representativeness for ecological validity depending on the way of the verification i.e., direct verification within an experiment, and indirect verification between previous and present experiments. Study I was based on the existing evidence of context dependence that participants’ responses differentiate in accordance with either typical laboratory or everyday-like context (see 1.1). Movements in the laboratory context are purposeless and externally triggered, while everyday life requires complex activities and serves certain purposes to movements. Previous studies in grasping movements have been criticized on the grounds that their experimental settings are not similar to everyday life (e.g., a computer game with joystick). Even though those studies discovered the effect of context dependence on grasping movements, it remained unclear whether the context dependence in that grasping movements would reflect in more everyday-like settings. Study I therefore tried to further compare grasping movement characteristics between a laboratory and an everyday-like context while performing a simulated grocery shopping task with a distal goal embedded in a movement sequence.

On the other hand, Study II dealt with the underpinning existing theoretical evidence of body turns with a distal goal. In Study II, the existing evidence implying that an ordered sequence of the eye-head-trunk turns while walking is regarded with a question of whether the ordered sequence remains or not if a distal goal is embedded in the movement sequence. Previous studies in this regard have demonstrated the existence of the ordered sequence based on explicit instructions and a proximal goal. For example, those participants were already aware of that their walk and turn movements are the ultimate goal of the task, so that they focused well on that walk and turn movements cued by a light or a beep (Ambati, Murray, Saucedo, Powell, & Reed-jones, 2013; Hollands et al., 2004; Patla et al., 1999). In everyday-life, however, walk and turns are normally executed in order to achieve an ultimate goal. Hence, Study II was initiated to compare data from the existing literature of the ordered sequence of body segment rotations with data from a more everyday-like setting in which there are proximal (grasping) and distal (walk and turn) goals concurrently.

* 1. **Second research question**

“The role of distal goals in different experimental settings”

Second research question deals with that if distal goals lead to same or different learning curves in different experimental settings. Study I and II were carried out in a simulated grocery shopping task in which participants’ kinematics were recorded and analyzed while they were forced actually to walk through the aisle, and then turn to the goal. Contrary to that, participants in Study III and IV faced a virtually simulated urban city through monitors, and their behavioral cognitive responses were analyzed by self-estimated tests.

Study III was regarded with the existing evidence in spatial knowledge while wayfinding that is typically acquired by three different types of knowledge as mentioned in *1.2.3*: landmark, route and survey knowledge. According to the framework of Siegel and White (1975), spatial knowledge about a new place develops over time from the initial stage of landmark knowledge to a stage of route knowledge to the final stage of survey knowledge. However, this framework has been criticized by the evidence implying that only circumscribed features and topological relations are encoded and stored during the early stages of learning, so that periods in which no metric information about distances and relative directions is stored exist ostensibly (Ishikawa & Montello, 2006; Montello, 1998). In response to these problems, Montello (1998) proposed an alternative framework that supports the existence of a parallel and continuous development of three types of knowledge rather than a stage-wise knowledge development.

Further from the threefold framework and the experimental settings of Study III, Study IV dealt with the effects of wayfinding practice on the distribution of visuo-spatial attention, and its age differences. Given that the attentional focus while wayfinding may occur as a gaze bias, gaze parameters such as fixation time, spread of gaze, and/or gaze time have been considered as important indicators for identifying the focus of participants’ attention during the tasks. Even though previous studies identified the effects of repeated practice on finding correct directions, or decreased gaze time throughout the trials, it remains unknown how and to what extent the direction of gaze is affected by repeated exposure to wayfinding tasks.

A complete overview of the research questions that have been arising based on the presented theoretical backgrounds is shown in Tab. 1.

**Tab. 1.** Overview of the research questions and the corresponding studies in which the question is addressed.

|  |  |  |
| --- | --- | --- |
| **#** | **Research Questions** | **Studies** |
| 1 | Are there differences in terms of the role of distal goals between when direct verification within an experiment, and when indirect verification between experiments? | I & II |
| 2 | Do distal goals result in different learning curves depending on experimental settings? | I - IV |

1. **STUDY I**

**Ecological validity of manual grasping movements in an everyday-like grocery shopping task**

**Kyungwan Kim & Otmar Bock**

Institute of Physiology and Anatomy, German Sport University Cologne

**Reference**

Kim, K. & Bock, O. (2019). Ecological validity of manual grasping movements in an everyday-like grocery shopping task. *Experimental Brain Research*, *237*(5), 1169–1177. https://doi.org/10.1007/s00221-019-05496-0

(Impact factor of journal in 2019: 1.591)

* 1. **Abstract**

In our earlier research, kinematic and kinetic parameters of grasping differed significantly when participants grasped the same object once in a traditional laboratory paradigm, and once as part of a captivating computer game. We attributed this finding to the fact that grasping movements in the laboratory were repetitive and meaningless, while those in the computer game were embedded in complex behavior and served a meaningful purpose. In that work, we argued that grasping in the computer game is more characteristic of everyday-life behavior; however, this conclusion has been criticized on the grounds that a computer game is not a typical everyday activity.

The present study therefore compares grasping in a traditional laboratory paradigm to that in an indisputably everyday context: grocery shopping. Thirty-three young adults executed externally triggered arm movements to grasp nondescript objects (laboratory task, L) and place them on a tablet, or they walked through a fictitious grocery store towards a shelf to grasp grocery products and placed them into a shopping basket (everyday-like-task, E). Size, shape, weight and location of to-be-grasped objects were identical in both tasks.

We found that of the analyzed 16 kinematic parameters, 13 differed significantly between tasks. Specifically, grip apertures were larger, movements were slower and grip-transport coupling was more variable in E compared to L. We conclude that kinematic differences between both persist even if task is more realistic than in our earlier research. Our findings are compatible with the notion that movement planning is less stringent in E than in L.

***Keywords*:** Ecological validity, manual grasping, grip aperture, context-dependence, grocery shopping

1. **STUDY II**

**Eye-head-trunk coordination while walking and turning in a simulated grocery shopping task**

**Kyungwan Kim, Madeleine Fricke & Otmar Bock**

Institute of Exercise Training and Sport Informatics, German Sport University Cologne

**Reference**

Kim, K., Fricke, M. & Bock, O. (2020). Eye-head-trunk coordination while walking and turning in a simulated grocery shopping task. *Journal of Motor Behavior*. 31, 1–8. https://doi.org/10.1080/00222895.2020.1811197

(Impact factor of journal in 2019: 1.279)

* 1. **Abstract**

Previous studies argued that body turns are executed in an ordered sequence: the eyes turn first, followed by the head and then by the trunk. The purpose of this study was to find out whether this sequence holds even if body turns are not explicitly instructed, but nevertheless are necessary to reach an instructed distal goal.

We asked participants to shop for grocery products in a simulated supermarket. To retrieve each product, they had to walk down and aisle, and then turn left or right into a corridor that led towards the target shelf. The need to make a turn was never mentioned by the experimenter, but it nevertheless was required in order to approach the target shelf. Main variables of interest were the delay between eye and head turns towards the target shelf, as well as the delay between head and trunk turns towards the target shelf.

We found that both delays were consistently positive, and that their magnitude was near the top of the range reported in literature. We conclude that the ordered sequence of eye- then head- then trunk turns can be observed not only with a proximal, but also with a distal goal.

***Keywords***: Eye-head-trunk coordination, steering control, proximal goals, distal goals

1. **STUDY III**

**Acquisition of landmark, route and survey knowledge in a wayfinding task: in stages or in parallel?**

**Kyungwan Kim & Otmar Bock**

Institute of Exercise Training and Sport Informatics, German Sport University Cologne

**Reference**

Kim, K. & Bock, O. (2020). Acquisition of landmark, route and survey knowledge in a wayfinding task: in stages or in parallel?. *Psychological Research*. https://doi.org/10.1007/s00426-020-01384-3

(Impact factor of journal in 2019: 2.419)

* 1. **Abstract**

According to an influential concept, humans acquire spatial knowledge about their environment in three distinct stages: landmark knowledge is acquired first, then route knowledge, and finally survey knowledge. The stage concept has been challenged by studies which observed that in a wayfinding paradigm, route and survey knowledge emerge at the same time and therefore were seemingly acquired in parallel. However, this experimental evidence is not conclusive because above studies suffered from a ceiling effect.

The present study was designed to overcome the ceiling effect by increasing the complexity of the wayfinding task. We asked 60 young participants to find their way through an urban environment rendered in virtual reality, and assessed their landmark, route and survey knowledge after each of ten trials.

We found that all three types of knowledge gradually increased from the first to the last trial. We further found that correlations between the three types of knowledge increased from trial to trial. This outcome disagrees profoundly with the stage concept, but is compatible with the parallel concept.

Specifically, it is in accordance with the view that landmark, route and survey knowledge are acquired by multiple overlapping and interacting processes: those processes may start out more or less independently in the first trial but, due to common constraints or synergies, may gradually increase their cooperation during subsequent trials.

***Keywords:*** Spatial knowledge, landmark knowledge, route knowledge, survey knowledge, wayfinding

1. **STUDY IV**

**Effects of practice on visuo-spatial attention in a wayfinding task**

**Mai Geisen1, Kyungwan Kim1, Stefanie Klatt1,2 and Otmar Bock1**

1Institute of Exercise Training and Sport Informatics, German Sport University Cologne, Cologne, Germany

2Institute of Sports Science, University of Rostock, Rostock, Germany

**Reference**

Geisen, M., Kim, K., Klatt, S., & Bock, O. (2021). Effects of practice on visuo-spatial attention in a wayfinding task. *Psychological Research*.

https://doi.org/ 10.1007/s00426-020-01463-5

(Impact factor of journal in 2019: 2.419)

* 1. **Abstract**

Several studies have evaluated the distribution of visuo-spatial attention in a wayfinding task, using gaze direction as an indicator for the locus of attention. We extended that work by evaluating how visuo-spatial attention is modified by wayfinding practice. Young and older participants followed prescribed routes through a virtual city on six trials. Each trial was followed by a route recall test, where participants saw screenshots of intersections encountered, and had to indicate which way to proceed. Behavioral and gaze data were registered in those tests.

Wayfinding accuracy increased from trial to trial, more so in young than in older persons. Total gaze time, mean fixation time, and the vertical scatter of fixations decreased from trial to trial, similarly in young and older persons. The horizontal scatter of fixations didn’t differ between trials and age groups. The incidence of fixations on the subsequently chosen side also didn’t differ between trials, but it increased in older age.

We interpret these findings as evidence that as wayfinding practice increased, participants gradually narrowed their attentional focus to the most relevant screenshot area, processed information within this focus more efficiently, reduced the total time in which attention dwelled on the rejected side of the screenshot, but maintained the total time on the chosen side. These dynamic changes of visuo-spatial attention were comparable in young and older participants. However, it appears that decision making differed between age groups: older persons’ attention dwelled longer on the chosen side before they made their choice.

***Keywords:*** Visuo-spatial attention, wayfinding, practice, gaze direction

1. **GENERAL DISCUSSION**

“Are there differences in terms of the role of distal goals between direct verification within an experiment, and indirect verification between experiments?”

The focus of the first research question across Study I and II was on determining whether the role of distal goals as a particular specificity for ecological validity represents differently depending on the direct (within an experiment) and indirect (between experiments) verification. Study I (*grasping in grocery shopping task*) was based on the direct verification, and revealed that the typical laboratory context, where participants were forced to focus only on a proximal goal, i.e., grasping objects in a standing position, showed a better performance than the everyday-like context where participants were required to focus on a distal goal while following proximal goals, i.e., walking, wayfinding and then grasping objects. Study I therefore reaffirms and expands the existing evidence that the grasping movement is characterized differently in the laboratory and the everyday-like context, even in a more everyday-like context. In the laboratory context, where standing preparation and artificial products were provided, participants showed a faster reaction time, more exact finger manipulation, and closer grip aperture than in the everyday-like context where an additional locomotive movement and real products were provided.

Study II (*body turns*) was based on the indirect verification, and compared the effects of distal goals on participants’ body turns while walking, with existing results based on proximal goals. Conducted in an even more naturalistic context, results of Study II regarding delay times (intervals between the onset of eye and head turns, and head and trunk turns) to the next corridor also reaffirm the existing results. Specifically, both delay times were consistently positive and their magnitude was near the top of the range reported in literature, so that the well-known ordered sequence of the eye-head-trunk coordination holds as demonstrated in previous studies. This result concludes that the ordered sequence of eye- then head- then trunk turns can be observed not only with a proximal, but also with a distal goal.

Given the results that both direct and indirect verification of the ecological validity based on distal goals reaffirm existing evidences from typical laboratory experimental environment, the use of distal goals when studying cognitive-motor skills seems to be conceivable as a particular specificity for arguing to what extent the results and the experimental settings are ecologically valid. And the existence of distal goals might have affected participants’ motivational and attentional focus that in turn may lead to better performance in context with only proximal goals than with proximal and distal goals concurrently. As described in 1.2, proximal and distal goals are based on different levels of performance that need to be achieved. Thus the concurrence of proximal and distal goals leads to the goal uncertainty that affects decision making not only before movement onset but also during movement execution. Given the assumption that such a multiple goal setting may induce everyday-like responses, the results of Study I and II suggest that the assumption is conceivable. So the use of distal goals resulted in the mediation of increasing participants’ intrinsic attentional and motivational focus to perform the tasks.

In terms of the attentional focus, *selective* and *divided* attention should be regarded with the cognitive-motor performance in everyday life situations. Behavioral studies have shown that attention is basically a selective process. Selective attention enables us to filter relevant information that is necessary for further processes so that the efficiency of the working process can increase. It also allows us to gather relevant information for optimizing our motor performance while overcoming the visual system’s limited capacity (Pestilli & Carrasco, 2005). On the other hand, divided attention focuses on multiple sources of information at the same time (Duncan, 1980). Thus, it is apparently affiliated with the ability to multitask, as they are commonly termed. The main issue of the divided attention is that we have a limited capacity to process multiple visual information at once. Direct verification of the role of distal goals in Study I showed different performance between laboratory and everyday-like context which might have arisen from the different attentional focus in both contexts (dominance of selective attention in L and of divided attention in E). Contrary to that, indirect verification with distal goals in Study II did not distinguish from the existing results with proximal goals, suggesting that there was none effect of attentional focus. This discrepancy between direct and indirect verification may be resulted from the complexity of the grocery shopping task with which will be dealt in next chapter (c.f. 7.2).

With regard to the motivational focus, two components of motivation, i.e., expectancy and autonomy of the movement performer, are thought to optimize motor learning and performance (Lewthwaite & Wulf, 2017). According to the OPTIMAL theory of Wulf and Lewthwaite (2016), participants’ autonomy is a particularly important component for the optimization of performance. When participants are being given autonomy, the motivational underpinnings of motor learning and performance benefits are enhanced (Lemos et al., 2017). Researchers have identified those benefits as ‘autonomy support’. Practice conditions that provide participants with autonomy support have exhibited higher effectiveness on motor learning and performance compared to conditions without the autonomy support (Lewthwaite & Wulf, 2012; Sanli et al., 2013). Given the autonomy support, distal goals might have shed light on how motor learning and performance can be optimized as realistic as possible. Specifically, the goal uncertainty through proximal and distal goals, and the absence of advance knowledge about the tasks through implicit instructions in Study I and II enhanced participants’ intrinsic autonomic motivation leading to naturalistic responses, so that their motor performances are thought to be ecologically valid.

However, the effects of autonomy can vary depending on the type of the tasks, as the attentional focus showed. Second research question is therefore regarded with the topic, if the role of distal goals varies in accordance with the experimental settings such as ‘task complexity’.

“Do distal goals result in different learning curves depending on experimental settings?”

Further from the first research question, second research question referred to the role of distal goals if repetitive practice shows different learning curves depending on experimental settings such as the task complexity. As described in 7.1, Study I and II were implemented in a simulated grocery shopping task in which participants’ kinematics were analyzed with regard to grasping and eye-head-trunk coordination during walk and turn. However, the experimental settings of the task were relatively simple, so that a rapid change of the learning curve was shown after the first exposure of the experiment, even though distal goals were embedded in the movement sequence. Thus, it was wondering if the learning curve based on distal goals may be affected by the increasing task complexity. Indeed, participants’ performance in Study III and IV showed gradually developed learning curves from the first to the last trials, whereas the performance in Study I and II showed striking change after the very first trial.

Study III (*spatial knowledge acquisition during wayfinding*) established that the existence of distal goals resulted in parallel acquisition of landmark, route and survey knowledge, and their continuous development across ten trials. This result supports the alternative framework (parallel acquisition of three types of knowledge) proposed in the last two decades rather than the dominant framework (stage-wise acquisition) which was initially proposed. Further from Study III, Study IV (*gaze distribution during wayfinding*) examined participants’ attentional focus throughout the same wayfinding task as in Study III, as well as with age differences. For that, participants’ behavior and gaze parameters were analyzed. Results revealed that participants showed increased performance in a route recall test across six trials, i.e., the increase of behavioral performance with age difference and the decrease of gaze distribution without age difference.

Strikingly, both studies showed different learning curves compared to Study I and II. This result might depend on the increasing task complexity, as assumed. Indeed, there was a fundamental difference between both the simulated grocery shopping task (Study I & II) and VR-City task (Study III & IV). The key point in Study III and IV was how well participants’ attentional focus can be transferred from the spatial information perceived from wayfinding in the VR-City on the treadmill (proximal goal) to the behavioral and gaze performance when static pictures captured from the VR-City are presented on the other monitor (distal goal). This indirect analysis differed from the direct analysis in Study I and II, where participants’ motor performance were recorded by the mobile eye tracker and the motion capture system during the learning phase simultaneously. Moreover, there was a particularly different task complexity between both tasks that the VR-City required participants to make a number of turns, and to remember a number of landmarks and routes, whereas the shopping task required them to find named products in the shelf after only one turn.

Particularly, both studies showed strikingly different movement characteristics between early and subsequent trials based on implicit learning modality: i.e., in early trials implicit learning modality remains, but it gradually transfers to a way of self-imposed explicit learning in subsequent trials because of the repetition of tasks. These results differ from typical laboratory studies providing explicit learning. Still, they are in line with the existing evidence of brain research suggesting that the memory system supporting learning modality refers to separate brain regions between explicit and implicit learning (Milner, Squire, & Kandel, 1998; Reber, 1992). Implicit learning refers to the non-declarative memory system that has been known to improve performance. In contrast, explicit learning depends on the declarative memory system that relates to the medial-temporal lobe (MTL) area in the brain. On the other hand, implicit learning consists of distinct operating characteristics, so that it may provide limited information processing, resulting in weaker performance than when explicit learning is activated (Sanchez, Gobel, & Reber, 2010).

Differences between explicit and implicit learning modality can also be explained by selective and divided attention. For example, the laboratory context in Study I induced participants to focus only on the objects to be grasped and the act of grasping itself, whereas the everyday-like context additionally required locomotion, so that participants’ attention was distributed onto irrelevant areas. Due to this, attention for cognitive-motor skills cannot be distinguished by one subset of attention, rather it can be characterized by multiple subsets of attention i.e., both selective and divided visual attention which are contrasting each other. Our real life requires divided attention because there may be numerous unexpected situations while we are focusing on a specific act. Those unexpected situations should be considered as irrelevant information that must be filtered out by selective attention to focus only on the specific act. In other words, implicit learning is necessary for conducting divided attention representing everyday attentional focus, and explicit learning is then needed to generate selective attention that can result in appropriate motor performance. However, it has been suggested that the capacity limitation depends on the visual discrimination which is the ability to recognize details in visual images: performance is not limited when visual discriminations are easy, but the limitation on capacity becomes apparent when visual discriminations are difficult (Kleiss & Lane, 1986; Treisman & Gelade, 1980). Compared to the selective attention, the limited capacity related to the divided attention can result in a decline in performance.

“Are studies of the present thesis ecologically valid?”

Study I confirmed the existing results, even though the task complexity increased. The results showed significantly different movement characteristics between the laboratory and everyday-like context. This result aligns with the evidence that performance on the verisimilitude approach would increase with increased functional skills, and with the focus of verisimilitude approaches on how well they capture the essence of everyday life characteristics (Chaytor & Schmitter-Edgecombe, 2003). Moreover, Study II that referred to the veridicality approach was compared with existing literature with regard to delay times between eye and head, and head and trunk during walk and turn. The ordered sequence of eye-head-trunk coordination was reaffirmed as reported in the literature.

Study III and IV may be considered as based on the verisimilitude of the ecological validity, because they were developed with having the theoretical similarity to everyday life in mind. In order to ensure ecological validity, more naturalistic stimuli, settings, and instructions were given, so that the overall task complexity increased compared to previous studies. Above all things, the concurrence of proximal and goals played the most important role in increasing the task complexity and the ecologically valid responses of the participants.

Based on the above results, both verisimilitude and veridicality approaches seem to be adequate to investigate ecological validity of a cognitive-motor task, especially when the task encompasses a distal goal or its combination with a proximal goal rather than when a proximal goal is solely given. This is in line with the evidence that the ecological validity is determined depending on the extent to which an experiment yields logically sound data representing an individual’s interaction with authentic surroundings (Chaytor & Schmitter-Edgecombe, 2003; Wallisch et al., 2018).

Given the lack of empirical rigor of verisimilitude approaches and the lack of theoretical rigor of veridicality approaches, both approaches should be complementary to each other. In other words, further studies for ecologically valid cognitive-motor performance using psychological and behavioral approaches should encompass the properties of both verisimilitude and veridicality simultaneously to address the mentioned lacks of each approach. Regardless of the role of both approaches in establishing ecological validity, the use of a distal goal with a proximal goal concurrently plays a role in deciding on how and which everyday behaviors should be investigated for the ecologically valid cognitive motor performance in exercise and experimental cognitive science.

To overcome those differences, experimental tools that can analyze cognitive and motor execution, such as mobile eye-tracking, motion capture, and mobile EEG, should be more suitable and widely used to derive results and experimental settings that are more similar to everyday life. In the last two decades, researchers have attempted to employ a microcosm of a more naturalistic research landscape based on everyday-like attentional focus (Kingstone et al., 2008; Risko & Kingstone, 2017; Risko, Richardson, & Kingstone, 2016; Zaki & Ochsner, 2009). The specific aim of those studies was to understand basic mechanisms underlying attentional focus as it is expressed in everyday life situations, and therefore to argue why naturalistic research methods are necessary. Much of the visual attention research is based on gaze movement patterns when facing static objects or scenes (e.g., Itti & Koch, 2000). This approach, however, has been criticized by the suggestion that selection in static objects or scenes obviously differ from selection in real objects or scenes (Foulsham & Kingstone, 2017). Nevertheless, it remained unclear how the transfer from dynamic scenes to static scenes would be facilitated.

1. **CONCLUSION**

Before the question is answered, whether distal goals are adequate specificity for determining ecological validity of cognitive-motor skills experiments, scientific results of each study in this thesis are summarized in Table 7.

**Tab. 7.** Overview of the scientific results of each study.

|  |  |
| --- | --- |
| **Studies** | **Scientific Results** |
| 1 | 13 of 16 kinematic parameters of grasping movement such as grip aperture, hand velocity or movement variability differed significantly between the laboratory (L) and everyday-like (E) context. This finding is in line with the existing evidence for context dependence based on a proximal goal. |
| 2 | Delay times between eye and head, and head and trunk turns towards the target shelf were consistently positive, and their magnitude was near the top of the range reported in literature. The ordered sequence of eye- then head- then trunk turns can be observed not only with a proximal, but also with a distal goal. |
| 3 | Landmark, route, and survey spatial knowledge, as well as their correlations increased gradually from the first to the last trial, even though distal goals were embedded in the behavioral sequence. This outcome is compatible with the parallel concept of spatial knowledge acquisition based on proximal goals. |
| 4 | As wayfinding practice increased, participants gradually optimized their attentional focus, even though distal goals were embedded in the behavioral sequence. Those results were compatible in young and older participants, whereas decision making differed between age groups. |

The present thesis highlighted the need for more naturalistic methods in the field of exercise science and experimental cognitive psychology by demonstrating the effects of distal goals embedded in behavioral sequences of cognitive-motor performance. In contrast to previous studies, participants were provided with implicit instructions and more naturalistic experimental settings to induce their focus on reaching distal goals as natural as possible, or finding goals voluntarily rather than focusing directly on proximal goals as generally.

Based on the results of the two research questions, the following overarching aspects can be concluded and the relevant outlooks are given:

1. Regardless of direct and indirect verification, the role of distal goals has an essential influence on cognitive-motor skills.
2. The role of distal goals, however, can be different depending on the experimental setting, in particular ‘task complexity’.
3. The use of distal goals in cognitive-motor skills is an appropriate approach, when there is a willingness to implement ecologically valid tasks.

However, how to control the effects of repetitiveness of the tasks, even in employing naturalistic methods in an everyday-like context, remains questionable. As a matter of fact, repetitiveness of the experimental tasks is indispensable for collecting statistically comparable data. However, our everyday life behaviors or movements normally do not involve such a repetition, so that we should consider how to replace the classical and conventional laboratory data collection methods. Thus, the challenge of future studies may be to develop a learning paradigm that is capable of producing robust implicit learning without concomitant explicit awareness.

* 1. **Relevance for Sport- and Exercise Science**

There is a growing appreciation in exercise science and experimental cognitive psychology for the observation and measurement of naturally and directly occurring behavior e.g., via mobile eye tracking (Kredel, Vater, Klostermann, & Hossner, 2017; Land & Tatler, 2009), mobile EEG (Ehinger et al., 2014; Sharma, Gramann, Chandra, Singh, & Mittal, 2017), virtual environment (Diersch & Wolbers, 2019; Kunishige et al., 2019), motion capture (Heyrman et al., 2013), or combining two measurements (Burger, Puupponen, & Jantunen, 2018; Lavoie et al., 2018; Miller et al., 2017). In other words, indirect measures through computerized tasks or conducting questionnaires while sitting on a chair, obstruct the acquisition of valuable insights through analyzing psychological and physiological aspects. Thus, indirect methods which require participants to remain in a seated position or present static pictures have been repeatedly criticized as the collection of natural behavior information is considerably restricted (Kredel et al., 2017). Such issues were exhaustively discussed by some studies regarding perceptual cognitive skills. These studies suggested that naturalistic environments and tasks are needed that mimic the complexity of the given task as close as possible (Gegenfurtner, Lehtinen, & Säljö, 2011; Mann, Williams, Ward, & Janelle, 2007). Hence, it seems necessary to pay attention to conducting an ecologically valid experimental environment and assessment.

In experimental cognitive psychology and sport science, the utility of employing more naturalistic methods is indeed a growing interest. The above mentioned technological advances enable us to observe naturally occurring behavior, to simulate real world environments better than before (Jovancevic, Sullivan, & Hayhoe, 2006; Land & Tatler, 2009), and to acquire deeper insights into important aspects of the human mind and movement (Risko & Kingstone, 2017). However, the newly developed technology apparently requires subjects’ multitasking ability, because two or more tasks are performed simultaneously (e.g., finding objects while walking, or being aware of the own position while wayfinding). Those situations which require multitasking ability may reflect part of our everyday life in which we need to divide attentional focus to multiple areas**.**

* 1. **Limitations**

Despite the importance of the reasonable coupling between distal and proximal goals, how to control the effects of repetition is an indispensable topic for the experimental research in exercise science and cognitive psychology. Repetition is a representative characteristic of typical laboratory tasks, which differ from our everyday life. As described before, participants were implicitly instructed during the first trial of Study I, and Study II, III & IV, so that they were not aware of what they had to do and what was tested in the everyday-like context. The experimenter did not give any additional information or instructions in subsequent trials. Rather, participants were required to autonomously figure out what “the ultimate goal” of the task is. Thus, participants’ expectant motivation derived from advance knowledge decreased, whereas their autonomic motivation increased, so that their attentional focus could be distributed around the whole experimental setting.

Taken together, in Study I, the involvement of distal goals actually differentiated between the laboratory and everyday-like context, with the effects of repetition being controlled by the expectancy and autonomy of the participants. Likewise, participants’ motivation across repetitive trials in Study II & III was appropriately controlled by the implicit learning and instructions. However, the attentional focus and the motivational level of participants may vary across individuals. Indeed, the analyses of the mean performance aggregated over all participants revealed relatively high standard deviations, suggesting that participants’ performance showed large individual differences. Some participants immediately identified the ultimate goal of the task and maintained a high level of performance throughout the experiment. Others showed poor identification of the ultimate goal and maintained a relatively low level of performance. Still, others exhibited intermediate performance for most of the experiment’s trials. These individual variations were particularly significant during the first trial in which pure and robust implicit learning was required.

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