An investigation of sequential motor learning in middle-aged and older adults
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General Discussion
The major aim of the present thesis was to assess the relative advantages and drawbacks of different amounts of instructions on the sequential motor learning in middle-aged and older adults. Indeed, even when having an active lifestyle, older but also already middle-aged adults show a weakening of cognitive and executive functions that are involved in motor learning. This may hinder motor learning, specifically when trying to put explicit detailed instructions to use (Chauvel et al., 2011; Chauvel et al., 2012; Durkin, Prescott, Furchtgott, Cantor, & Powell, 1995). Enhancing understanding on motor learning is the more important, given that middle-aged and older adults are making up an increasingly large proportion of the work force. Hence, the current thesis focus is on adults aged between 50 and 65 years (i.e., middle age and older adults), rather than elderly people beyond 65 years, who’s motor functioning is more often the topic of scientific scrutiny. In view of the (long-term) aim to generalize the findings to realistic work situations, the current investigations adopted standard laboratory tasks, but also tasks that are more representative for practice. Accordingly, sequential motor learning was scrutinized not only because of a large scientific backdrop, but also its high relevance for peoples’ capacity to cope with a constantly changing (working) environment. In addition, except for examining the typical performance increases after different types of learning interventions, the thesis also investigated the resilience of performance after learning when transferred to different circumstances (e.g., performing an additional task simultaneously, or encountering (slight) changes in task sequence). This final chapter will first summarize and discuss the observed impact of different learning interventions (i.e., different amount of explicit instructions) on sequential motor learning in middle-aged and older adults (i.e., Chapters 2, 3 and 4), and secondly, the resilience of motor performance after learning for different types of transfer (Chapters 2, 4 and 5). Next, some propositions for future research questions, which are pertinent for a better understanding of sequential motor learning in middle-aged and older adults,
but remained unanswered in the current thesis, will be provided. The chapter will conclude with practical recommendations regarding sequential motor learning for middle-aged and older adults.

**The role of instruction in middle-aged and older adults’ sequential motor learning**

As stated repeatedly in this thesis, the amount and detail of the instructions given to endorse learning affect a learner's level of awareness and explicit knowledge regarding what is learned. In the case of sequential motor learning, the order of the different movements that need to be executed can be plainly exposed to the learners, ensuring that they are consciously aware of the sequence they must learn. This sequential motor learning is labeled as explicit. Hence, during explicit sequential motor learning, the learner becomes aware and accumulates declarative knowledge about the movements required towards a clearly defined goal. By contrast, the to-be-learned motor sequence can also not be fully revealed and remain hidden to the learner. In this implicit sequential motor learning, learning does not call for reflection and is typically guided by external stimuli that prevent the learners from focusing on and becoming aware of the exact sequence they are producing. That is, in implicit sequential learning, the learner does not build any explicit knowledge regarding the to-be-learned motor sequence. Previous, studies have shown that cognitive processes that are tightly linked to consciousness, such as attention and working memory are negatively affected by ageing (Hommel, Li, & Li, 2004; Jenkins, Myerson, Hale, & Fry, 1999). Consequently, a basic premise is that with increasing age it may become more troublesome to learn explicitly than implicitly. However, evidence for this conjecture is still limited in case of sequential motor learning (D. V. Howard & Howard, 2001). Accordingly, in Chapter 2 the alternating serial reaction-time task, a modified version of the traditional laboratory-based serial reaction-time task, was used to further scrutinize this conjecture. The findings indeed
showed that implicit sequential motor learning remained unaffected in middle-aged and older adults, while explicit sequential motor learning was reduced when compared to younger adults. This experiment thus showed that the ability to benefit from explicit instructions reduced with age, suggesting that implicit learning is the more suitable learning intervention in middle-aged and older adults. Importantly, however, a follow-up study pointed out that the time the middle-aged and older participants had available to use the explicit instructions might have played a significant role in the observed loss of efficiency of explicit learning. Indeed, when the time constraint was reduced and more time was available between responses, some of the middle-aged and older participants were able to benefit from explicit instructions. Yet, trouble remained to exploit explicit knowledge for learning beyond a certain time constraint. By contrast, implicit learning remained intact whatever the time constraint. In short, more than merely showing that implicit learning remains relatively intact in middle-aged and older adults while explicit learning is degraded, these findings emphasize the mediating role of time constraints on the expression of explicit learning during ageing. It must be noted, however, that the efficiency of implicit learning among middle-aged and older adults should be taken with caution as some studies showed that when implicit sequential motor learning involved more prolonged practice, age-related declines also emerged (for a review see J. H. Howard & Howard, 2013).

Willingham (1998) argued that motor learning growths out of (changes in) motor control processes. In this respect it is pertinent that the different learning methods, invoke different control process, which may be differently affected by age. Explicit learning requires voluntary, goal-directed control processes, while implicit learning is supported by automatic, stimulus-driven control processes (Reber, 1989, 1992). Given that only explicit learning was mediated by time constraints, Chapter 3 examined whether this can be attributed to a differential slowing down of the voluntary and automatic
control processes in middle-aged and older adults. To this end, participants performed a series of pointing tasks in both age groups. This included the anti-pointing task, in which participants had to point to a target: when it moved, participants had to point to the side opposite to which the target shifted. Doing so required them to intentionally suppress the automatic stimulus-driven adjustment towards the shifting target. The study revealed that voluntary goal-directed adjustments (i.e., the anti-pointing) are delayed in middle-aged and older adults compared to young adults. It could not be clearly established whether the automatic stimulus-driven adjustments were affected as well, but it was clearly the case that the age-related slowing down was greater for the voluntary adjustments. Ageing thus slows down the voluntary control process that presumably supports explicit learning to a larger extent than the automatic control process, which is thought to underpin implicit motor learning. The experiment also showed that during anti-pointing, the automatic adjustment toward the target shift was sometimes intentionally suppressed (Cameron, Cressman, Franks, & Chua, 2009; McIntosh, Mulroue, & Brockmole, 2010). This cognitively demanding suppression (McIntosh et al., 2010), however, was less effective among the older participants, which may point to a further cognitive weakening in middle-aged and older adults in the face of increased cognitive demands. To sum up, Chapter 3 reinforces the relevance of time constraints in considering the capacity for explicit motor learning in middle-aged and older adults. Indeed, with a markedly slowed down voluntary goal-directed control process, the use of explicit instructions for motor learning would logically require more time among middle-aged and older adults; that is, younger adults can benefit from explicit instructions under more challenging time constraints. Thus, when provided sufficient time, middle-aged and older participants should still have the opportunity to benefit from accumulating explicit knowledge to improve motor performance as much as younger adults.
Chapter 4 assessed the effect of explicit instructions on sequential motor learning in a task that was self-paced; that is, there were no external time constraints, but participants were allowed to choose their own pace. Additionally, by adopting a commercially available workstation that aims to guide workers toward assembling components into a product, the representativeness of the learning task for the labor context was enhanced. The study manipulated the amount of the instructions regarding the to-be-learned sequence, comparing the custom detailed instructions via text and pictures with a less explicit visual guidance method. Contrary to predictions, the middle-aged and older adults that received the more encompassing explicit instructions showed an equivalent rate of sequential motor learning as the ones that were given less explicit details regarding the sequence to learn. Furthermore, the more encompassing explicit instructions even led to better consolidation. Possibly, and in line with the suggestion in Chapters 2 and 3, the absence of the time constraints (i.e., the self-pacing) in the assembly task may have greatly promoted the benefit of explicit instructions in the middle-aged and older adults.

**The effects of transfer after middle-aged and older adults’ sequential motor learning**

Once learned, a motor task may be executed in conditions that are different from practice, and thus call for the ability to adapt. For example, in a work place, the surroundings can be noisy and distracting, or the task may undergo slight changes. Hence, an important measure for the quality of motor learning in middle-aged and older adults is the resilience of sequential motor learning against the various types of transfer.

Chapter 2 and 4 explored transfer to dual tasking conditions: the sequential motor task remained intact but a new context imposed an additional cognitive load by requiring the participants to perform a concurrent second task. It was hypothesized that due to the reduced working
memory functioning, which is typically observed with ageing, the ability of middle-aged and older adults to deal with a secondary task would be negatively affected when compared to young adults, and the more so, for the more explicit learning interventions. Chapter 2 used an auditory tone identification task. It was found that although tone identification was similar among groups, age-differences did arise in the primary motor task after learning with explicit instructions. That is, scrutiny of the few older participants that were capable of learning explicitly showed that motor performance was not resilient against the introduction of the secondary task. This suggests that after explicit sequential motor learning middle-aged and older adults loose the flexibility needed to resist interference from dual tasking. Yet, it seems that this reduced transfer cannot be uniquely attributed to poorer working memory functioning. Instead, it may also reflect relatively weak representations of the motor sequence (i.e., possibly due to the imposed time constraints, see above). Similarly, after implicit sequence learning, the motor performance was disrupted under dual tasking conditions in both age groups. This is consistent with earlier findings (Jimenez, Vaquero, & Lupianez, 2006) indicating that the weak representations stemming from implicit learning cannot resist contextual change. Because sequential motor learning completely disappeared after implicit learning in both age groups, no conclusion could be drawn regarding the influence of ageing on the transfer of implicit sequential motor learning during dual task. Chapter 4 also assessed transfer to dual tasking. To do so, it was evaluated whether listening to an auditory track (i.e., for which they were told they would have to recall certain details) while performing the sequential manual assembly task affected motor performance after learning. Like the findings for consolidation (see above), the middle-aged and older adults seemed to perform better during transfer to dual tasking after having practiced with more explicit instructions. That is, unlike young adults who showed no differences, the middle-aged and older adults only maintained stable motor performance (i.e., movement time)
following the more explicit learning intervention. Recall of the details of the auditory track, however, was jeopardized compared to the younger adults. The middle-aged and older adults that underwent the less explicit guidance did show reduced motor performance following transfer to a dual task. Yet, their ability to recall details of the track was retained relative to the young adults. Middle-aged and older adults’ ability to handle dual tasking and prioritization of the two tasks seems to depend on the amount of explicit instruction during practice.

In sum, Chapter 2 and 4 show that middle-aged and older adults are less flexible in dealing with transfer to a secondary task than younger adults. This reduced flexibility arose irrespective of the presence of time constraints and also (although in different forms) independent of the amount of explicit instruction. Together, this might point to a general decline in the ability to manage dual task among middle-age adults, perhaps due to the weakening of working memory functioning.

Chapter 5 explored transfer to (learning) partially different sequences. Both the benefits and/or interferences of a learned motor sequence on the learning of a new, similar but slightly different motor sequences (i.e., proactive transfer) were assessed. Conversely, the effects of the newly learned motor sequence on the similar but slightly different previously learned sequence (i.e., retroactive transfer) were also scrutinized. To do so, participants successively learned to assemble two different products, consisting of six components. Two pairs of consecutive components moved to a different location in the sequence depending on the product to build. After learning the second sequence, participants were again required to assemble the first product. It was found that ageing had a greater impact on retroactive (i.e., reproducing the previously learnt sequence after learning the second) than on proactive transfer (i.e., learning a second sequence after having learnt a similar but not identical sequence). Middle-aged and older participants were less capable than younger adults to produce the product
learned on the first day after learning the second product, indicating increased retroactive interference. In fact, the younger adults who did not show any interference (i.e., they could perfectly recall the initial product) actually gained speed on those parts of the sequence that were common to both products; however, middle-aged and older participants did not. With respect to proactive transfer, middle-aged and older participants appeared to benefit from sequential motor transfer while younger adults did not. Yet, it must also be noted that young participants managed to reach levels of learning for the first product that were superior to middle-aged and older adults. Hence, the apparent benefit of proactive transfer among the older group may more likely be a side effect from a reduced learning rate of the middle-age and older adults rather than a genuine age-related difference in proactive transfer. Thus, although ageing indisputably impacts retroactive transfer (i.e., increased interference and less facilitation); it may be more neutral to proactive transfer (with certainly no indications of any adverse effects).

**Recommendations for future research and practical implications**

Although the current thesis showed that implicit sequential motor learning and related control processes are relatively spared among middle-aged and older adults when compared to explicit sequential motor learning in a laboratory task, it also points to possible advantages of more explicit and detailed instructions for sequential motor learning of middle-aged and older participants for representative, but simple tasks (i.e., manual assembly). The practical task researched in the present thesis allows for relatively easy transfer to workstation task with relatively fixed end products to be built without stringent external constraints. However, this is illustrative for only one type of task in the production industry. Other tasks, such as manual picking or assembly tasks using conveyer bands may be more difficult to generalize to because they do typically impose time constraints on the
workers’ motor learning and performance. Yet the present thesis suggests that detailed explicit instructions to enhance sequential motor learning are much more problematic for middle-aged and older workers in these time-constrained task. Clearly, future work must further assess the learning for a greater spectrum of motor sequences both in terms of complexity and time constraints. In addition, it should go more systematically beyond the typical serial reaction time tasks to uncover how these and other tasks characteristics and instructions modulate motor learning in middle-aged and older adults. Doing so, would allow the determination of the type of learning intervention that would best benefit middle-aged and older adults for a larger variety of situation.

Continuous empirical efforts are also needed regarding the effects of ageing on transfer to circumstances other than in practice (i.e., to dual tasking, structural changes in the sequence, but also fatigue, anxiety and so on). An important methodological issue for this future is to examine transfer both as a function of the amount of practice and the amount of learning (i.e., setting a learning criterion). That is, delineating genuine age-effects may require more prolonged practice among middle-aged and older adults than younger adults. Our studies, for example, might not have allowed the older participants a sufficient amount of practice to reach a learning state comparable to a study by Chauvel et al. (2012), which did find that performance after implicit learning of golf task was less affected in older adults, and used longer practice periods. Yet, these differences may also be attributed to the sequential nature of the golf task being more natural (or less arbitrary), and hence, warranting less (explicit) guidance than the current experimental tasks. Anyhow, at present any conclusions regarding differences in transfer between young and older adults must be considered tentative, because the older adults showed reduced levels of sequence learning.

Finally, it should also be noted that reported results gives a grasp on the type of process that start to be affected among active middle age adults
(i.e., 50-65), and although informative regarding the dynamic of ageing, these results cannot be transferred to old/sedentary adults.

Based upon current results, although still relatively preliminary, some practical recommendation regarding interventions for sequential motor learning for middle-aged and older industrial workers are feasible, particularly for settings that allow them to set their own work pace. That is even though sequential motor leaning becomes less adaptive from middle age onwards, varying the tasks constraints under which a motor sequence is learnt may actually help to retain learning flexibility. For example, learning would be promoted by allowing them sufficient time to address and implement the instructions. In fact, in doing so, detailed instructions regarding the sequence to learn may actually lead to more permanent performance enhancement and larger resistance against distractions. Finally, regarding sequential motor transfer, it might be wise to avoid tasks that can invoke retroactive transfer.