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Verneau, M.M.N.

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Introduction
Introduction to sequential motor learning in middle-aged and older adults

Sequential motor actions may sound a bit exotic, but they are crucial in daily life. Indeed, as adults we are thoroughly accustomed to perform sequential motor actions each day; for instance when getting dressed, preparing breakfast, or at work later where we built products or type documents. These activities have been repeated so many times that we are typically not aware that they in fact consist of series of actions that are linked together. We perceive the task as a whole rather than as sequential. Yet, when confronted with new tasks or new machines or equipment, often a new prescribed sequence of actions needs to be accomplished for successfully achieving our goals. For example, when I moved from France to the Netherlands, I had to learn new sequences of actions to accustom myself typing on a QWERTY keyboard, using the pedals to brake on a classic Dutch bike and so on. Adapting to the new Dutch environment thus greatly relied on my capacity for sequential motor learning. Nevertheless, in general the adaptation did not require much effort: the fact that I do not remember that many examples perhaps suggest that I mostly learned without being aware. With ageing, however, efficacy of motor learning declines, making adaptations more effortful for middle-aged and older adults. In fact, I bet that when they would visit me in France, my supervisors would struggle much more to learn the new sequences required by the infamous AZERTY keyboard than I did learning the QWERTY keyboard. Indeed, research shows that as early as 50 years old, adults start to need more practice to reach performance levels similar as younger adults (Schwerha, Wiker, & Jaraiedi, 2007; Seidler, 2006), or put differently, start to show less performance gains than younger adults after same amounts of practice (Shea, Park, & Braden, 2006; Voelcker-Rehage &
Willimczik, 2006). Interestingly, Voelcker-Rehage (2008) argued that the age-related decline in motor learning efficacy is not absolute however. That is, depending on the structure, complexity and difficulty of the task, the observed decline in learning efficacy in middle-aged and older adults can be minimized or enlarged. Also the degree of familiarity with slightly different tasks may affect learning effectiveness. This ‘selective’ impact of ageing may be attributed to differences in the processes that are called upon when learning tasks with different characteristics, because ageing affects some of these processes more than others. In particular, research points to the weakening of cognitive abilities as a major limiting factor in middle-aged and older adults’ motor learning (Craik & Bialystok, 2006). Pertinent cognitive abilities (or executive functions) like attention, memory and inhibition slow down, get less efficient or become more effortful (for a review see Ren, 2013). Cognitive ageing begins in early adulthood for attention and memory processes (Hommel, Li, & Li, 2004; Salthouse, 2004) and in middle adulthood (i.e., from 50 years of age) for other executive functions like inhibition (Mathis, Schunck, Erb, Namer, & Luthringer, 2009). Learning a motor sequence is thought to involve these executive functions. Indeed, to achieve learning, cognitive resources have to be actively allocated to the correct targets (i.e., involving attention and inhibition), while the to-be-produced motor sequence must be kept in the working memory. Due to its reliance on conscious processes, this type of sequential motor learning is called explicit learning.

Interestingly, however, learning of sequential motor actions can also be achieved with no or only minimum reliance on cognitive abilities. A particularly elegant paradigm to show this implicit learning is the Serial Reaction Time task (SRT-task). In the SRT-task, participants respond to series

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1 As an aside, this probably means that the rate of motor learning is typically negatively correlated with ranking of the authors of a scientific paper.
of different visual stimuli by pressing the corresponding key as quickly as possible. When confronted with ordered and random sequences of visual stimuli, people gradually come to respond faster to the ordered sequences than to the random sequences, also when they are not aware that (part of) the sequence is recurring (Nissen & Bullemer, 1987). Hence, by repetitively performing the same sequence, participants incidentally learn the motor sequence, even if they are not informed and do not notice that there is regularity in the sequence. Learning without the learner being aware of what is learned is called implicit learning (Reber, 1989, 1992).

Although over the past 20 years the capacity for implicit sequential motor learning has been firmly established in the scientific literature, the traditional approach that is typically adopted in practice still strongly relies on types of explicit learning that invoke conscious cognitive abilities. For example, when confronted with a new machine, users typically follow (written) manuals with detailed depictions of the individual steps that make up the task. Such learning procedures are also common in industrial work places. Presumably, users learn the task by consciously accumulating knowledge. This may become more difficult with age. Importantly, however, several studies adopting the SRT-task have reported that when completely oblivious to the to-be-learned motor sequence, middle-aged and older adults can still learn and sometimes do so as effectively as younger adults (Bo & Seidler, 2010; Fraser, Li, & Penhune, 2009; D. V. Howard & Howard, 1989, 1992). Interestingly, it has been suggested that when instructed about the details of the order of the sequence, older adults clearly underperform compared to uninformed older adults, while the performance of younger adults does not differ as function of instruction (D. V. Howard & Howard, 2001). However, this conjecture has not being investigated very thoroughly.

In this thesis, I will investigate sequential motor learning and its underlying control processes in middle-aged and older adults (i.e., 50-65 years old) with an eye on the amount of instructions that are provided to
support learning (Chapter 2, 3 and 4). Accordingly, a major aim of this thesis is to assess the relative benefits (or draw backs) from implicit and explicit interventions in sequential motor learning for middle-aged and older adults. Although most research on sequential motor learning focused on older adults (i.e., 60 and beyond), we also involved middle-aged adults because cognitive abilities may start to decline as early as 50 years. This is not only of theoretical importance, but also may have pertinent social implications. Nowadays, society is changing at a progressively rapid rate, resulting in a constant need to learn (slightly) new tasks in order to adapt to the ever-changing environment during our - increasingly longer- lifespan. More specifically, European policies are developed to face the adverse effects of the ageing population. Among others, these policies address the increasing age of the working force in the western society\(^2\) coupled with a growing use of new technologies in the work place (Marquardt & Kearsley, 1999). In this respect, investigations of sequential motor learning among middle-aged and older adults are particularly relevant. For this reason, the thesis not only adopts the conventional SRT-task (Chapter 2), but also examines manually assembly tasks, as these require more complex motor actions that are representative for daily activities (Chapters 4 and 5). Finally, the current thesis’ focus towards real-world issues is also reflected in the investigation of the flexibility of sequential motor performance after learning in the face of potentially disrupting influences such as performing a second task (dual tasking, Chapters 2 and 4) or learning a slightly different task (proactive and retroactive transfer, Chapter 5). In the remainder of the current chapter, I briefly outline the experimental studies that are reported in the subsequent chapters.

\(^2\) The 55-64 rose from 37% of the work force in 2000 to 46% in 2009 (European Agency for Safety and Health at Work he European council project to raise this proportion to 50% across Europe).
The current thesis: a preview

Several SRT-studies demonstrate that implicit sequential motor learning remains relatively effective with ageing, provided that the order of the sequence is not too complex (Bennett, Howard, & Howard, 2007; D. V. Howard & Howard, 1989, 1992; D. V. Howard et al., 2004; J. H. Howard & Howard, 1997; J. H. Howard, Howard, Dennis, & Yankovich, 2007). Interestingly, however, it has been suggested that when older adults are instructed that there is a repeating order within the sequence then learning is negatively affected. By contrast, the same instruction does not hinder performance among young adults (D. V. Howard & Howard, 2001). Yet, advising that “a” pattern exists still requires discovering the particulars of the order. It is unknown, however, if the difficulties with explicit learning among older adults also occur when they are notified about the order of the sequence. Moreover, the efficacy of explicit and implicit sequential motor learning has not yet been examined for middle-aged adults. Therefore, Chapter 2 compares implicit and explicit sequential motor learning in healthy young adults and adults between 50 and 65 years old using the Alternative Serial Reaction Time task (ASRT-task, see Figure 1), which is a variation of the traditional SRT-task with a more complex pattern (J. H. Howard & Howard, 1997). For explicit learning, participants were fully informed about the details of the sequence. In addition, resilience against dual tasking and muscular fatigue after learning was assessed. In a follow-up experiment, it was examined to what degree manipulation of task constraints may reduce the suggested adverse effects of explicit learning among older adults; in particular, the experiment assessed whether explicit learning in middle-aged and older adults is promoted when more time is available to use the explicit instructions. From a practical point of view, it is significant to know whether or not adjusting the time available to use explicit knowledge helps dissolve any age-related differences in learning.
Figure 1: Illustration of the ASRT task experiment with on the left side the experimental apparatus composed of the E-prime response box and its four available keys. Behind the box, a flat screen displays a row of four circles. Each circle corresponds to one of the keys (from left to right, the circles correspond to keys 1, 2, 3 and 4, respectively). The right side of the figure depicts an example of the alternate sequence that occurs during the ASRT (i.e., the red numbers form the to-be-learned ordered sequence, while the black numbers denote the randomly generated number interspersed in the ordered sequence).

In anticipation of the results reported in Chapter 2, middle-aged and older adults were indeed found to be less efficient learners, especially under an explicit learning regime under high time constraints. These findings drew attention to voluntary conscious control processes slowing down with age, rather than becoming less precise or accurate. To further substantiate this claim, Chapter 3 seeks to find out whether indeed the voluntary conscious motor processes slow down more with age than the implicit automatic processes. To this end, the anti-pointing paradigm was adopted, which has never been fully employed to assess age-related differences (Rossit & Harvey, 2008; Sarlegna, 2006). In the anti-pointing paradigm, participants reach for
targets that may or may not shift location after the onset of the reach. Participants are instructed to either reach into the direction of the new location (i.e., pointing) or into the opposite direction (i.e., anti-pointing). The anti-pointing condition, however, has been shown to trigger two types of adjustments (see Figure 2). Typically, a first involuntary adjustment toward the shift, presumably supported by implicit automatic motor processes, is followed by a slower conscious adjustment in the intended opposite direction (Cressman, Cameron, Lam, Franks, & Chua, 2010; Day & Lyon, 2000; Veerman, Brenner, & Smeets, 2008). The latter adjustment is thought to be supported by voluntary conscious motor processes. Chapter 3 examines the hypothesis that the voluntary motor process (i.e., adjustment toward the opposite direction) slow downs more with age than the implicit automatic motor processes (i.e., first unwanted adjustment) by comparing middle-aged and older adults' performance to young adults' performance on the anti-pointing task.

**Figure 2:** Illustration of the hand trajectory (red line) during the anti-pointing condition when the target jumps from the centered location to the left side of the screen. The hand trajectory before the jump is dashed.
The first experimental chapters examine whether the time scale on which explicit learning operates is an important parameter in the ability of middle-aged and older adults to profit from instructions. Yet, although time is often an important factor in manual work as for instance assembly work, it rarely involves the severe time pressure in order of magnitude of 100ms as encountered by participants in the ASRT-tasks. Moreover, these and other daily activities generally involve more complex movement dynamics (i.e., more degrees of freedom and visual guidance, see for a more elaborate argument Steenbergen, van der Kamp, Verneau, Jongbloed-Pereboom, & Masters, 2010). Hence, to draw genuine conclusion about the capacity for explicit learning in daily activities, sequential motor learning should also be assessed in more representative tasks that release sequential motor learning from an unlikely high tempo. Yet, in considering more realistic tasks that engender sequential motor learning, issues arise concerning the feasibility and utility of an entirely implicit learning process.

That is, learning a new motor sequence while remaining fully oblivious to its details seems hardly achievable or useful in many applied tasks. Nevertheless, manipulating the cognitive load during learning can be achieved by using more or less detailed instructions, which would require different degrees of cognitive engagement. Indeed, the suitability of typically very detailed instruction in user manuals can be compared to an instructional design that potentially alleviate reliance on cognitive processing (e.g., by visually guiding the learner through the sequence). Hence, Chapter 4 compares the effects of different types of instruction in middle-aged and young adults’ sequential motor learning in a self-paced task representative for industrial work (i.e., the manual assembly task see Figure 3). The impact of the different type of instructions is assessed immediately after practice and after at least 24 hours to examine the consolidation of the performance improvements. It is expected that middle-aged and older adults benefit more when the amount of explicit instructions is limited.
Finally, the efficacy of motor learning not only involves the performance gains (or stability), but also the capacity to transfer the learned motor sequence into similar but slightly different motor sequences. For example, in the manual assembly industry workers are often required to switch back and forth from building one product, which is produced by assembling components in a certain order, to a second product in which components are assembled in a slightly different order. Hence, Chapter 5 addresses the effects of ageing on transfer after learning the same sequential motor assembly task as per Chapter 4. On separate days, the two age groups learn two motor sequences that are partly the same. Transfer of sequential motor learning is addressed by examining how the learning of the two sequence mutually influence each other. These influence involve proactive and retroactive transfer. Proactive transfer concerns the positive or negative effects of a previously learned sequence on a new sequence, whereas retroactive transfer refers to the positive or negative effects that learning of a new sequence has on the earlier acquired sequence. The degree of interference (negative effects of transfer) and facilitation (positive effects) are assessed as a function of age. Chapter 6 concludes the thesis by overviewing the main results of the experimental chapters and providing recommendations for further research and practice.

Figure 3: The Assembly Task Apparatus (ATA©) used in Chapter 4 and 5. Participants are instructed to assemble prescribed products out of 6 components.