An investigation of sequential motor learning in middle-aged and older adults
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2016

document version
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2

Age and time effects on implicit and explicit learning

It has been proposed that effects of aging are more pronounced for explicit than for implicit motor learning. The authors evaluated this claim by comparing the efficacy of explicit and implicit learning of a movement sequence in young and older adults, and by testing the resilience against fatigue and secondary tasking after learning. It was also examined whether explicit learning in older adults can be promoted by alleviating time constraints during learning. The alternating serial reaction time task (ASRTT) was used. Experiment 1 compared the benefits of receiving full instructions about the stimulus sequence relative to receiving no instructions in young (20-25 years) and older (50-65 years) adults during retention and during transfer to fatigue and secondary task conditions. Experiment 2 alleviated time constraints during the initial bouts of practice with full instructions. Experiment 1 indicated that the older adults learned on the ASRTT, and achieved similar performance as young adults when no instructions were given. In contrast to the young adults, learning was not superior in older adults who received full instructions compared with those who did not. Experiment 2 indicated that alleviating time constraints allowed some of the older adults to gain from instruction but only under relatively low time constraints, but there was no retention with rigorous time constraints. Explicit learning, but not implicit learning, declines in older adults. This is partly due to older adults difficulties to apply explicit knowledge. Less rigorous time constraints can help to ameliorate some of these difficulties and may induce levels of explicit learning in older adults that will result in superior performance compared with implicit learning. Implicit learning did occur under time constraints that prevented explicit learning.
Introduction

Many human activities consist of repetitive sequences of movements. In the assembling industry, for example, workers put together products by picking up and mending its components in a prescribed order. However, when new products are introduced, actions need to be adjusted, often requiring new movement sequences. This industrial practice raises questions, not only regarding the most effective way of learning, but also with respect to how different learning strategies affect the vulnerability for adverse conditions such as fatigue and distraction (e.g., concurrently performing a cognitive task). In our aging society it is pertinent to specifically relate this to older adults as well. For example, it has been reported that learning movement sequences to assemble new products declines with age (Hancock, 1967; Schwerha, Wiker, & Jaraiedi, 2007).

Motor learning, including the learning of repetitive sequences of movements, has traditionally been described as involving a mandatory early stage during which a learner consciously acquires knowledge about the structure and dynamics of the movement. However, the past two decades has seen a surge in research that highlighted the plausibility of motor learning being incidental without the active accrual of movement knowledge. Cleeremans and Jiménez (Cleeremans & Jiménez, 2002) argued that the key distinction between these explicit and implicit modes of learning is the strength, distinctiveness and stability of the representations that are involved. According to this view, explicit learning involves more distinctive and stronger representations allowing the learner to exert conscious control over the learning processes. Consequently, explicit learning enables flexible control over actions in complex, unpredictable environments. Implicit learning arises from weak representations that are insufficiently strong to exert conscious control, but still allow enhanced adaptation to a particular set of task demands. In this respect, implicit learning results from selective attention to individual stimuli without consciously taking the more global patterns
between stimuli into account. Consequently, implicit and explicit learning have distinct properties. First, implicit learning is typically more robust in exploiting weak or non-salient stimuli (e.g., when task relevant information is hidden by non-relevant information) that cannot be accessed by consciousness, whereas explicit learning breaks down when perception of stimuli is compromised. Second, implicit learning is specific to the context in which learning occurs, while explicit learning confers flexibility in addressing contextual changes. Jiménez and co-workers (Jiménez, Vaquero, & Lupianez, 2006; Jiménez & Vazquez, 2005), for instance, examined motor learning on a serial reaction time task (Nissen & Bullemer, 1987) and found that after implicit learning performance was negatively impacted by alteration of task-context (e.g., performing a secondary task); however, the alteration did not deteriorate performance after explicit learning. By contrast, explicit learning led to a reduced performance compared to implicit learning when the acquired explicit knowledge was ostensibly no longer valid (i.e., when a sudden change of the sequence was introduced).

Numerous theorists have drawn attention to a possible decline of explicit learning with aging relative to implicit learning (Reber, 1992). This decline has commonly been attributed to stronger dependence of explicit learning on working memory for conscious storage and manipulation of declarative knowledge about the movement structure and dynamics (Maxwell, Masters, & Eves, 2003; Steenbergen, van der Kamp, Verneau, Jongbloed-Pereboom, & Masters, 2010). Unlike the stimulus-driven process (Deiber et al., 2010) implicated in implicit learning, working memory processes are found to deteriorate with age (Salthouse, 1990; Wingfield, Stine, Lahar, & Aberdeen, 1988), resulting in less distinctive and weaker knowledge representations. Accordingly, several authors have reported that implicit processes result in effective learning among older adults on the serial reaction time task (SRTT; Bo & Seidler, 2010; Cherry & Stadler, 1995; D. V. Howard & Howard, 1989, 1992), perhaps even to levels similar as found in young adults.
Strictly speaking, however, this research did not always demonstrate unequivocally that learning was in fact implicit or explicit (D. V. Howard & Howard, 1992). Hence, in subsequent work more complex sequences, in which ordered and random stimuli were alternated (alternating serial reaction time task [ASRTT]), have been used to avoid awareness of the regularities after implicit learning (Bennett, Howard, & Howard, 2007; D. V. Howard et al., 2004; J. H. Howard & Howard, 1997). Older adults were found able to learn the ASRTT implicitly, but no direct comparison was made with explicit learning regimes. There is one exception, however. Howard and Howard (D. V. Howard & Howard, 2001) concluded that incidental learning (i.e., implicit learning regime) on the ASRTT was superior over intentional learning (i.e., explicit learning regime). Unfortunately, post-experimental recognition tests could not confirm that the older adults (and some of the younger adults) had obtained declarative knowledge about the sequence after intentional learning. The failure in inducing explicit learning after intentional instructions might be due to the fact that only partial information about the presented sequence was provided. Consequently, it still remains to be proven that implicit sequential motor learning is less affected by aging than explicit sequential motor learning. Moreover, most studies focused on performance during practice, which gives insight how performance evolves through practice but leaves out the issue to what degree the performance increments are retained after practice in the absence of the particular instruction or feedback context. It has been shown that performance differences during practice are not always indicative for performance differences during retention (Salmoni, Schmidt, & Walter, 1984; Shea & Kohl, 1990). Only with performance retention after practice, it can be claimed that learning occurred. Therefore, the primary purpose of the current study is to assess the relative effectiveness of implicit and explicit learning of a sequential movement task in older adults, at the end of practice and after practice during retention.
The assessment of whether learning is achieved implicitly or explicitly has proved to be a major methodological issue. Free recall reports and recognition tasks may not render all the conscious knowledge that is accrued or not only knowledge that is conscious (Shanks & St John, 1994). Jiménez et al. (Jiménez et al., 2006) have therefore proposed to also use transfer tests that may indicate qualitative performance differences after learning. Implicit learning, for instance, relies on selective attention and its expression therefore depends on the preservation of task context, while explicit learning results in enhanced flexibility to avoid disruption of the performance by the introduction of task-irrelevant stimuli (Cleeremans & Jiménez, 2002). Hence, the introduction of a secondary task after learning should negatively impact performance on the SRTT following implicit learning but not or less after explicit learning (Jiménez et al., 2006; Jiménez & Vazquez, 2005; Shanks, Rowland, & Ranger, 2005). Consequently, transfer to a condition in which participants perform a SRTT concurrently with a second task permits an assessment as to whether learning was intentional (i.e., whether participants were able to develop and use explicit knowledge about the sequence) or more incidental. Even though this may provide further insight in the relative benefits of explicit and implicit learning, transfer to a secondary task condition after SRTT learning has not been assessed in older adults.

In addition, also the converse can be assessed: transfer to a condition that preserves task context may be less disruptive after implicit learning (Jiménez et al., 2006). In this regard, performance after implicit learning is reported to be more resilient against psychological pressure and fatigue (Masters, 1992; Masters, Poolton, & Maxwell, 2008; Poolton, Masters, & Maxwell, 2007). For instance, an incidental practice procedure (by gradually

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3 There is a growing body of motor learning literature that in fact reveals greater robustness against dual tasking being conveyed after implicit learning compared to explicit learning (Chauvel et al., 2012). Possibly these discrepant findings are related to differences in task constraints. Rather than externally paced timing tasks as the SRTT, these studies mostly adopted self-paced far aiming tasks such as golf putting and ball-throwing.
increasing task difficulty) led to more stable performance on a rugby ball-throwing task under conditions of anaerobic and aerobic fatigue compared to intentional or explicit learning (Masters et al., 2008; Poolton et al., 2007). Hence, transfer to conditions of fatigue can be used as a marker for assessing the degree to which explicit knowledge is developed and used during SRTT learning, also in older adults.

To summarize, the current study investigated whether, as proposed by Reber (1992), implicit learning is spared with age relative to explicit learning. To this end, learning in groups of young and older adults on an ASRTT was assessed. Participants in the explicit learning groups were fully instructed about the details of the presented sequence. Participants of the implicit learning groups were not informed about the presence of a sequence, while the second order nature of the sequence would in all likelihood prevent the participants from discovering the regularity. Participants’ learning was assessed at the end of practice, but importantly also after practice in typical retention tests and in transfer tests to secondary task and fatigue conditions. This not only would provide insight in relative stability of the products of learning between the two age groups, but in addition to the usual free recall and recognition tests, provide the possibility to verify existence of qualitative differences in the knowledge acquired through the explicit and implicit practice regimes.

In line with earlier, but not fully substantiated suggestions from previous work (e.g., D. V. Howard & Howard, 2001), it was hypothesized that aging goes together with decline in explicit learning, due to the deterioration of cognitive processes involving working memory. Implicit learning, by contrast, would not be adversely affected by age (see also Chauvel et al., 2012). It was further predicted that the transfer to a secondary task condition, which alters the context irrelevant to the task (i.e., a tone identification task), would lead to worse performance for the implicit than for the explicit learning groups (Jiménez et al., 2006). Yet, given the deterioration of working memory
processes with age, the older adults but not the young adults may also show some secondary task interference after explicit learning, although this should be reduced relative to implicit learning. Finally, it was expected that transfer to a fatigue condition, induced by repetitive forceful squeezing of a bulb object, is more likely to affect ASRTT performance after explicit learning than after implicit learning because it leaves the task context unaltered (Jiménez et al., 2006; Poolton et al., 2007).

EXPERIMENT 1

1-Method

1-1 Participants
Twenty young adults between 20 and 25 years of age (mean age = 22.5, sd =2.7 years) and eighteen older adults between 50 and 65 years of age (mean age 58.6, sd =3.6 years) participated in this experiment. Participants’ characteristics are reported in Table 1. The participants were divided in four groups: young adults instruction group, young adults no-instruction group, older adults instruction group, and older adults no-instruction group. Participants were right-handed, had normal or corrected to normal vision, and reported that they were not on medication and did not suffer from chronic pain of the forearm, shoulder and/or hand. They received a small monetary reward for participation. The local institution’s ethical committee approved the study. The participants were naive to the purpose of the experiment, but were fully debriefed after its completion.

1-2 Apparatus and stimuli
The sequence of ordered and random stimuli was shown on a 19 inch LCD screen (170B Philips). The presentation was controlled by E-prime 2 (Psychology Software Tools, Inc.). The participants responded to the stimuli using the five-key serial response time box that accompanied the E-prime 2 software. The response box was placed directly below the screen, but to the
right of the participants' midline such that their right arm was in a comfortable posture for pressing the keys. Colored stickers with numbers 1 to 4 were attached to the keys to simplify instruction. The fifth key was not used and covered by black tape. The corresponding stimulus array consisted of four black circles (23 mm in diameter) presented horizontally (distance between midpoints 51 mm) at the screen's center. The target stimulus turned green, while the three remaining circles were filled grey like the background. The start of stimulus presentation (i.e., target circle turning green) was triggered by the key press with a fixed response-stimulus interval (RSI) of 100ms. The maximum duration of stimulus presentation was set to 900ms.

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*Table 1: Participants characteristics for experiment 1 and 2: level of education (i.e., number of years spent in the scholar system), self-rated health (rated from 1 till 5 with 5 being very healthy) and the scores for the digit span (WAIS-iii (1)) and the digit symbol substitution tests (WAIS-iii (2)). ** indicates difference for age (p < 0.01).*

For the transfer to the secondary task condition, random sequences of low pitch (i.e., 440 Hz) and high pitch tones (Schumacher & Schwarb, 2009) were presented using speakers. The duration for each tone was 40ms. Coinciding with the visual stimuli, randomly a low, a high or no pitch was sounded. In total, thirty-two pitch tones were generated for a block of 80
stimuli (see below). The total duration for the transfer to secondary task block was identical to that of the retention test. A MacBook Pro microphone was used to record vocal answers. To induce and determine fatigue for the second transfer test, the participants repeatedly squeezed the pump bulb from a hand force transducer (TSD114-MRI, BIOPAC Systems Inc.), the force of which was concurrently presented on the LCD-screen in front of the participants. A YAMAHA quartz metronome QT-1 was used to set the cadency of hand squeezes (i.e., 1.6 Hz).

1-3 Procedure and design

The participants performed an alternating serial reaction time task (ASRTT). They were seated in front of a computer screen and instructed to respond as quickly as possible after presentation of the green stimulus circle by pressing the spatially corresponding key on the response box. The presented sequence of stimuli was of a second order nature, in which random (r) and ordered stimuli (1, 2, 3 or 4) were shown in alternation (e.g., if the sequence to learn was 3,2,1,4 then the displayed stimuli will be 3-r-2-r-1-r-4-r, 3-r-2-r-1-r-4-r and so on, see J. H. Howard & Howard, 1997). The r-stimulus could be any 1, 2, 3 and 4 randomly assigned by E-prime 2. Participants were instructed to use the index, middle, ring and little finger of their right hand to press key 1, 2, 3 and 4, respectively. Participants were randomly assigned to one of the six possible ordered sequences.

The experiment consisted of two sessions. At the start of the first session, the participants were randomly assigned to either the no-instruction group (i.e., presumably resulting in implicit learning) or the instruction group (i.e., presumably resulting in explicit learning), and received general instructions on task procedures and design. Specifically, they were told that the aim of the experiment was to ‘assess how the response times of the fingers evolve during repetitive motor performance, and how this is affected by distraction and fatigue’. The participants then completed two WAIS-iii subtests (i.e., working memory capacity and processing speed, see D. V.
Howard & Howard 2001). This was followed by instructions specific to the learning intervention. In the no-instruction group, participants were told to press the key that spatially corresponded to the green target stimulus as accurately and as fast as possible. They were not informed that every other target stimulus was part of an ordered sequence. The participants in the instruction group were told that an ordered sequence of target stimuli was interspersed among random stimuli, and received the full details of the order. They then learnt the sequence by heart. To ensure that the participants would actually use this knowledge, it was emphasized that using it would lead to superior performance at the end of the second session, even if it may seem to hinder performance initially. They were also told that the participant with the greatest performance increase over the two sessions would earn an additional 15 Euro reward.

After receiving the instructions, the participants familiarized themselves with the task by responding to two blocks of 12 random stimuli. In the first familiarization block, feedback was provided after each response as to whether the correct key was pressed. In the second block, feedback was abolished. The first practice phase started 1 minute after completing the familiarization block. It consisted of 25 blocks that contained 10 repetitions of the sequence made up of eight stimuli (e.g., 3-r-2-r-1-r-4-r). To reduce the likelihood that the participants of the no-instruction groups became aware of the sequence, each block started with a random stimulus. Taken together, in this practice phase (as in the second, see below), the participants responded to a total of 2000 stimuli (i.e., 80 stimuli x 25 blocks). No feedback was provided. After each block there was a 30 seconds break. Before the start of each new block, the participants in the instruction group were reminded to use their knowledge of the sequence.

The second session, which took place at approximately the same time on a different day no more than three days later, started with three familiarization blocks. The first two blocks were identical as in the first
session. During the third familiarization block of 12 random stimuli, the participants also had to carry out a tone identification task. They were required to call ‘low’ or ‘high’ when they heard a low or high tone respectively. This was to briefly familiarize the participants with the secondary task procedure. After a 1-minute break, the participants practiced another 25 blocks of 80 stimuli as during the first session (i.e., without tone identification). Before starting these practice blocks, the participants of the instruction groups rehearsed the details of the sequence.

After a 5-minute break, the experiment continued with the test phase, which consisted of a retention test followed by a transfer to fatigue condition, a second retention test, and finally a transfer to a secondary task condition. In the first retention test, the participants performed one block of the ASRTT (made up of 10 repetitions of the sequence of 8 stimuli) as quickly and accurate as possible but without any further instruction or feedback. Subsequently, the participants were subjected to the fatigue protocol. The protocol involved two minutes of exercise to tire the flexor muscles of the fingers. To this end, the participants first squeezed the pump bulb with maximal force. This was repeated twice with one minute of recuperation in between. The highest delivered force was taken as the maximal voluntary pressure (MVP). During the two minutes exercise that followed the participants were required to repetitively squeeze the pump bulb with a force of minimally 30% MVP at a cadence of 1.6 Hertz indicated by the metronome. The actual force and the 30% MVP criterion level were shown on the screen. The participants rated the perceived exhaustion (PE) on a 10 points Borg Scale at 30, 60, and 90 seconds during the exercise and at the end of the exercise. The fatigue protocol was concluded with two final squeezes of maximal force. The difference with the MVP was used as the measure of fatigue. Immediately afterwards, the participants performed one block of the ASRTT for the transfer to fatigue condition. After 5 minutes of rest, during which the participants were asked to complete a general questionnaire, they
performed the second retention composed of one block of the ASRTT. A final block of the ASRTT served as the transfer to secondary task condition. During this block the participants had to concurrently identify tones by calling 'low' or 'high' when they heard a low or high tone respectively.

After the test phase, a recognition test and an interview were administered to evaluate the explicit knowledge that was developed and used to perform the ASRTT (J. H. Howard, Howard, Dennis, Yankovich, & Vaidya, 2004). The recognition task assessed the participants' ability to recognize or distinguish the learned sequence of stimuli. To this end, the participants were presented with 20 sequences of 16 stimuli. Half of these sequences corresponded to the practiced ASRTT sequence of 8 stimuli presented twice, the remaining half were sequences of 16 random stimuli. The ordered and random sequences were randomly presented. The participants of the no-instruction groups were asked to rate each sequence to the extent they thought they had encountered it in any phase of the experiment from 1 ('I am certain it did not') to 5 ('I am certain it did'). The participants of the instruction group were asked to rate each sequence to the extent that it was the learnt sequence using a similar scale from 1 ('I am certain it is not the learnt sequence') to 5 ('I am certain it is the learnt sequence').

The interview probed awareness of the sequence with increasingly specific questions about the order in the stimulus sequences (J. H. Howard et al., 2004). This interview was only conducted for the no-instruction group, since the instruction group was informed repeatedly about the order of the stimuli sequences. Instead, these participants were asked whether or not they had actually tried to use the knowledge about the order of the stimuli sequence. They were also asked to recall the sequence to verify that they had actually learnt it.

1.4 Data analysis
To assess the degree of learning, response accuracy and response time (RT) were determined for the ordered and random stimuli separately. Only RTs for
Correct responses were included for analysis. For the final practice block and each test block, the difference between random and ordered trial in response accuracy (i.e. ΔRA) and response time (i.e. ΔRT) was calculated. Frequently, learning is assessed through the evolution of Δ’s during practice. Yet, to make sure that increments during practice are relatively permanent and also retained when the (explicit) instruction regimes are removed, the main assessment of performance and its stability was in retention and transfer tests after practice, but included a comparison with the final practice block. First, to examine learning as a function of age and instruction for the last practice block and the first retention test, ΔRA and ΔRT were submitted to 2 (Age: younger adults, older adults) x 2(Instruction: instruction, no-instruction) x 2 (Test: final practice block, first retention test) ANOVAs with repeated measures on the last factor. In this and all other analyses, the significance criterion was set at α = 0.05. Huyn-Feldt corrections for the p-values were reported, in the case that the sphericity assumption was violated. Partial eta-squared (η_p^2) values were computed to determine the proportion of total variability attributable to each factor or combination of factors. Post-hoc comparisons were performed using t test with Bonferroni corrections. For each group two-tailed one-sample t tests (with test value = 0) were conducted to establish whether the ΔRAs and ΔRTs for the separate tests differed from zero. Second, stability of learning was assessed by comparing performance in both transfer tests with the preceding retention test. Accordingly, ΔRA and ΔRT were submitted to 2 (Age: younger adults, older adults) x 2(Instruction: instruction, no-instruction) x 2 (Test: second retention, transfer to secondary task condition) and to 2(Age: younger adults, older adults) x 2(Instruction: instruction, no-instruction) x 2(Test: first retention test, transfer to fatigue condition) ANOVAs with repeated measures on the last factor. In addition, two-tailed one-sample t tests (with test value = 0) were conducted to establish whether the ΔRAs and ΔRTs for the transfer tests differed from zero.
With respect to the recognition task, percentage of ‘good hits’ and ‘I don’t know’ were calculated. Ratings were categorized as ‘good hits’ when the sequence was either correctly identified as being part of the ordered pattern of stimuli (i.e., ‘I am certain it did’ [5] and ‘I think it did’ [4]) or correctly identified as not being part of the ordered sequence of stimuli (i.e., ‘I am certain it did not’ [1] and ‘I think it did not’ [2]). The remaining ratings (i.e., ‘I am not certain’ [3]) were categorized as ‘I don’t know’. Both percentage scores were submitted to separate 2(Age: younger adults, older adults) x 2(Instruction: instruction, no-instruction) ANOVAs.

2- Results

2-1 Performance after practice: learning

Figure 1 shows the evolution of response time during practice with the 50 practice blocks collated into epochs of 5 blocks. Generally, it illustrates that the response differences for the ordered and random stimuli arise early during practice and gradually increase, attesting that participants improved performance on the ASRTT. It illustrates that by the end of practice the differences in response time for ordered and random stimuli appear much more pronounced in the instruction group than in the no-instruction in the younger adults but not in the older adults. To verify these differences, performance in the final practice block and the first retention test was assessed.

Response accuracy The analysis of variance did not reveal any significant effects for ΔRAs, F’s < 2.8, p’s > 0.09. Moreover, separate one-sample t tests for the different groups showed that ΔRAs did not exceed zero, neither in the final practice block in any group, nor in the first retention test, t’s < 2.00, p’s > 0.05. The scores of ΔRA never exceeded 4.5%.

Response Time Figure 2 shows that the difference in response time between the random and ordered stimuli (i.e., ΔRT) is most pronounced for the young adults in the instruction group. Nevertheless, the remaining groups
also show consistent differences in response time between the random and ordered stimuli, albeit smaller. Accordingly, the analysis of variance revealed significant effects of Age, $F(1, 34) = 6.6, p < 0.05, \eta_p^2 = 0.16$, Instruction, $F(1, 34) = 6.0, p < 0.05, \eta_p^2 = 0.15$, and Age by Instruction, $F(1, 34) = 5.5, p < 0.05, \eta_p^2 = 0.14$. No effects for Test were found, $F's < 2.6, p's > 0.11$. Post hoc indicated that $\Delta$RT was larger among the instruction than the no-instruction group, but only for the younger adults. By contrast, the older groups did not differ as a function of instruction. Post hoc also indicated that the two age groups exhibited different $\Delta$RTs with instruction, but similar $\Delta$RTs without instruction. In addition, one-sample t tests evaluating whether $\Delta$RT for the four groups exceeded zero indicated that $\Delta$RTs were significantly different from zero for each group in both the final practice block, and the first retention test, $t's > 2.7, p's < 0.05$, except for the older group without instruction in the last practice block, $t(8) = 2.26, p=0.054$.

![Figure 1](image-url)  

**Figure 1:** Response time for young adults instruction group (a), young adults no-instruction group (b), older adults instruction group (c), and older adults no-instruction group (d) as a function of practice epochs (i.e., first epoch (E1), second epoch (E2) etc.) and stimulus type (i.e., random (.) and ordered (—)) in Experiment 1.
Explicit knowledge assessment For the recognition task, the analysis of variance on the percentage of ‘good hits’ showed significant main effects of Age, $F(1, 34) = 4.6, p < 0.05, \eta^2_p = 0.12$, Instruction, $F(1, 34) = 47.2, p < 0.001 \eta^2_p = 0.58$, and Age by Instruction, $F(1, 34) = 4.5, p < 0.05 \eta^2_p = 0.12$. Post hoc comparisons indicated that percentages of good hits were higher in the instruction groups (i.e., 88%) than in the no-instruction groups (i.e., 39.5%). In addition, in the instruction groups the older adults had fewer ‘good hits’ than the younger adults (i.e., 64% and 88%, respectively) while for the no-instruction groups no age-related difference emerged. Finally, two-tailed one-sample $t$ tests showed that the older adults (like of course the younger adults)
in the instruction group were significantly above chance (i.e., 50%), \( t(8) = 2.83, p < 0.05 \). For the ‘I don’t know’ responses, only a significant effect of Instruction was found, \( F(1, 34) = 18.2, p < 0.001, \eta_p^2 = 0.35 \). The instruction groups provided fewer ‘I don’t know’ responses (i.e., 4%) than the no-instruction groups (i.e., 21%).

During free recall, none of the participants of the no-instruction groups reproduced part of the ordered sequence, whereas all participants of the instruction groups correctly recalled the entire sequence. However, the older adults in the instruction group all commented being unable or having difficulties applying this knowledge during both the practice and test blocks.

**2-2 Stability of performance after learning: secondary task**

To assess the stability of performance after learning as a function of age and instruction, we compared response accuracy and response time for the first retention test and the transfer to secondary task condition, and for the second retention test and the transfer to fatigue condition (see below). To this end, only the main and interaction effects for Test are reported.

*Response accuracy* The analysis of variance revealed a significant main Test effect, \( F(1, 34) = 6.1, p < 0.05, \eta_p^2 = 0.15 \), as well as a significant Test by Age interaction for \( \Delta RA \), \( F(1, 34) = 5.5, p < 0.05, \eta_p^2 = 0.14 \). Post hoc revealed that younger participants exhibit a higher \( \Delta RA \) than older participants during the second retention. This age difference disappeared during the transfer to secondary task condition. However, separate one-sample \( t \) tests for each of the four groups showed that \( \Delta RAs \) did not exceed 0 in the transfer test or second retention test, \( t's < 1.9, p's > 0.05 \), except for the young instruction group that showed significant \( \Delta RAs \) for the second retention test, \( t(9) = 2.38, p < 0.05 \).

*Response Time* It is clear from Figure 2 that transfer to the secondary task not only increased response time, but also considerably reduced the difference between random and ordered stimuli. Accordingly, significant effects of Test, \( F(1,34) = 17.2, p < 0.001, \eta_p^2 = 0.33 \) and Test by Learning
$F(1,34) = 6.1 \quad p < 0.05, \quad \eta^2 = 0.15$ were found. Post hoc indicated that the difference in $\Delta$RT between the groups with and without instruction disappeared during the transfer to secondary task condition. However, one-sample $t$ test over each of four groups revealed that for the young instruction group $\Delta$RT was significantly larger than zero in both the second retention test and the for the transfer to the secondary task, $t's > 2.20, p < 0.05$. By contrast, for the three remaining groups the significant $\Delta$RT in the second retention test had disappeared in the transfer to secondary task condition, $t's < 1.60, p > 0.05$.

*Tone identification* Differences between groups in $\Delta$RT on the transfer tests might be attributed to differences in performance on the secondary task. However, participants were accurate in discriminating low and high tones. The younger and older adults correctly identified 88% and 83% of the tones, respectively. The analysis of variance did not reveal any significant effects, $F's<2.3, p's > 0.13$.

**2-3 Stability of performance after learning: fatigue**

*Response accuracy* The analysis of variance did not reveal a significant effect by Test over $\Delta$RAs, $F's < 2.8, p's > 0.09$. One-sample $t$ tests for each of four groups and tests separately showed that $\Delta$RAs never exceeded zero, $t's < 2.10, p > 0.05$.

*Response Time* The analysis of variance did not reveal significant effects of Test for $\Delta$RTs, $F(1, 34) = 0.03, p = 0.86$. Yet, one-sample $t$ tests showed that all four groups in both the first retention test and the transfer to fatigue condition had $\Delta$RTs that were significantly larger than zero, $t's > 2.80, p< 0.05$.

*Level of fatigue* The absence of any effects of fatigue might be attributed to unsuccessfully manipulating fatigue. However, two-tailed one-sample $t$ tests (with test value = 0) on the percentages of reduction in MVC induced by the fatigue protocol (i.e., calculated by dividing the difference between the MVCs in pre- and posttest by the MVC in the pre-test multiplied
by 100) were significant for each of the four groups, \( t's > 3.80, p's < 0.05 \), indicating that the participants of all groups were indeed fatigued. In addition, the analysis of variance on the percentage of reduction in MVC revealed no significant differences for Age or Instruction, \( F's < 0.22, p's > 0.63 \). Finally, the analysis of variance for the perceived exertion did only reveal a significant effect of Time, \( F(3, 102) = 198.3, p < 0.001 \). No effects for Age or Instruction were found, \( F's < 1.1, p's > 0.29 \). Post-hoc indicated that perceived exertion significantly increased with every interval of 30 sec.

### 3- Discussion

Reber (1992) argued that incidental or implicit learning would be relatively spared from the adverse effects of aging in comparison to explicit learning. Accordingly, the older adults in the current study did show learning on the sequential movement task (i.e., indicated by significantly shorter response time for ordered than random stimuli during retention), but contrary to the younger adults, the learning was not superior for participants that received full instructions about the stimulus sequence (see also D.V. Howard & Howard, 2001). This was not only the case for the final practice block, but also for the retention tests, indicating that the differential improvements in performance during practice were retained in the direct absence of the instructional regimes. In other words, it seems that the younger adults benefitted more from the instructions than did the older adults. This difference could not be attributed to differences in the trade-off between response speed and accuracy among the young and older adults. Yet, before concluding that unlike implicit learning, explicit learning is indeed degraded among older adults, we have to ascertain that learning in the no-instruction and instruction groups was indeed achieved through implicit and explicit learning, respectively.

Among the young adults, the evidence clearly supports this. The participants in the instruction group demonstrated better recognition of (parts of) the sequence of the ordered stimuli than the participants in the no-
instruction group, who did not show any indication of having accumulated explicit knowledge of the regularities in the ASRTT. In addition, learning of the sequential movement task was maintained during the transfer to a secondary task condition for the instruction group (i.e., the difference in response times for ordered and random stimuli decreased significantly compared to the retention test, but was still larger than zero), whereas for the no-instruction group the concurrent secondary task resulted in a breakdown of performance (i.e., equal response times for ordered and random stimuli). Previous studies have reported a comparable enhanced resilience to secondary tasking of explicit relative to implicit learning (Jiménez & Vazquez, 2005; Jiménez et al., 2006; Shanks et al., 2005), indicating that the provision of task-relevant information indeed induced explicit learning in young adults. It is consistent with the proposal that explicit learning but not implicit learning confers flexibility in exerting conscious control to address contextual changes. Transfer to fatigue did not affect the young adults’ response times. This was expected for the no-instruction group, but not for the instruction group (see also Masters et al., 2008; Poolton et al., 2007). Possibly, the fatigue protocol was insufficiently task-specific. We conclude that the current instruction regimes did indeed elicit explicit and implicit learning in the young adults.

For the groups of older adults, the interpretation of results is less straightforward. Clearly, the older adults that received instructions on the regularities of the stimuli sequence did accumulate some explicit knowledge (cf. D.V. Howard & Howard, 2001), but less than the young adults did. Moreover, they reported having difficulties applying the knowledge in both the practice and the test phases of the experiment. In addition, in older adults the transfer to a secondary task condition resulted in a breakdown of performance for the no-instruction as well as the instruction group (i.e., equal response times for ordered and random stimuli). Thus, the (supposedly) explicit knowledge that older participants in the instruction group accrued did not allow them to deal with the altered task-context, raising doubts that
learning was indeed explicit. Alternatively, this breakdown may reflect a decline in working memory functioning that prevents them from performing two tasks at the same time (Gothe, Oberauer, & Klugl, 2007; Hartley & Little, 1999). Similar to the observations in the younger adults, the transfer to fatigue did not disrupt performance of the older adults, neither in the instruction nor in the no-instruction groups. Yet, it was predicted that performance after implicit learning would be more stable than after explicit learning as long as the task-context is preserved (Cleeremans & Jiménez, 2002), perhaps questioning the suitability of the present fatigue protocol for reaction time tasks. Hence, learning among the older participants that were informed about the sequence group may have been (partially) explicit, but was clearly less effective. This is supported by considering participants’ sensitivity to chunks of three stimuli (so called triplets) that repeatedly occur during practice.\(^4\) The triplet analysis distinguishes triplets that are not part of the to-be-learned sequence and that occur frequently (i.e., random consistent) or infrequently (i.e., random inconsistent), and triplets that are part of the to-be-learned sequence and thus occur frequently (i.e., patterned)(for more details of this type of analysis, see D.V. Howard et al., 2004). The critical comparison to assess the use of explicit knowledge is between sensitivity to random consistent and patterned triplets, with the later indicating the ability to actually use explicit knowledge. This analysis shows that only the young instruction group developed sensitivity specific to the ordered sequence of stimuli\(^5\). Hence, even though they were aware of the ordered pattern of stimuli, the older instruction participants were not able to exploit this

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\(^4\) Obviously, triplets occur much less frequently than individual ordered and random stimuli (i.e., triplets consist of combinations of individual stimuli). Therefore, their occurrence is too infrequent to reliably analyze them over blocks of 80 trials (as in the retention test). Hence, we analyzed triplets by combining five blocks of practice (i.e., an epoch).

\(^5\) Submitting the response time to 2(Age) x 2(Instruction) x 10(Epoch) x 3(Triplet) analysis of variance with repeated measures on the last two factors revealed a significant Age by Instruction by Triplet interaction, $F(2,68) = 9.3$, $p < 0.005$, $\eta^2_p = 0.21$. Post-hoc indicated that for each of four groups response times were significantly larger for random inconsistent triplets than random consistent and patterned triplets. Response times for the random consistent triplets only differed from the patterned triplets in the young instruction group, with the patterned triplets having shorter response times.
knowledge to anticipate ordered stimuli. In fact, they exhibited similar responses time as the participants that did not receive instructions (i.e., sensitivity to the most repeated triplets), confirming what they reported during the interviews. Hence, the older instruction group apparently learned the sequence implicitly as attested for by non-sequence specific sensitivity to frequently occurring chunks of stimuli and the complete breakdown of performance in the transfer to secondary task condition.

In sum, the present findings demonstrate that explicit learning, but not implicit learning is negatively affected by age. However, the degree to which explicit learning declines is not entirely clear. Unlike previous work, the current findings do provide some evidence for the occurrence of explicit learning in older adults (e.g., above chance recognition of parts of the sequence, correct free recall), but its products were relatively weak and unstable, and their performance also shared features of implicit learning. In fact, Cleeremans and Jiménez (2002) suggested that the differences between implicit and explicit learning should be considered as graded rather than as ‘all-or-nothing’. Within the graded perspective, the current outcomes may be interpreted as showing that learning with instructions in older adults shares more characteristics with ‘pure’ implicit learning than in young adults, resulting in less flexible control over behavior.

The weakening of cognitive functioning in older adults is often attributed to decline in working memory functioning and/or slowing down of cognitive processes (D. V. Howard & Howard, 1992; Verhaeghen & Salthouse, 1997). This may hinder or prevent older adults from adopting cognitively demanding strategies in sequential motor learning. For example, in a series of studies, Verwey and colleagues (Verwey, 2010; Verwey, Abrahamse, Ruitenberg, Jiménez, & de Kleine, 2011) showed that problems in explicit learning relate to the incapacity of older adults in creating chunks of successive stimuli. Interspersing random between ordered stimuli, as in the current ASRTT, may in fact be more cognitive demanding, and thus may have
further exacerbated the problems for older adults. Importantly, however, there are convincing arguments that organismic constraints (such as working memory functioning) impact behavior always in interaction with task constraints (Newell, 1986). This raises the issue as to whether the reduced performance of older adults after learning with instructions is caused by degradation of explicit learning per se, or whether it reflects the interaction with task constraints. Therefore, Experiment 2 will alleviate the time constraints of the ASRTT by introducing longer RSI during early practice. During further practice, the RSI is gradually decreased to eventually match the rigorous RSI of Experiment 1.

**EXPERIMENT 2**

Experiment 1 suggested that explicit learning was adversely affected in older adults. Most likely, this was related to a degraded capacity to actually use the knowledge about the order of the sequence rather than to older adults having difficulty remembering the order (although recognition was worse than in young adults). In Experiment 2, therefore, the participants learned the ASRTT with instructions, but under less rigorous time-constraints in the first practice blocks (i.e., longer intervals between response and subsequent stimuli (RSI)). During practice, time-constraints were gradually made stricter through a decrease of the RSI after every 5 blocks, starting from 1100 ms to 100 ms in the final blocks. This would allow the participants initially more time to become aware of the order in the presented stimuli sequences and to exploit their knowledge to improve response accuracy and time. We expected that this would lead to better recognition for the older adults to levels similar as the young adults. In turn, we hypothesized enhanced explicit learning in older adults, which would be revealed by stable ASRTT performance after practice (also when confronted with a concurrent secondary task) that is superior to
the performance observed in the older adults in Experiment 1 (i.e., the instruction group).

1- Method

1-1 Participants
Thirteen young adults between 20 and 25 years of age (mean age = 22.6; sd = 1.8 years) and sixteen older adults between 50 and 65 years of age (mean age = 55.2; sd = 3.9 years) were recruited. Participants’ characteristics are reported in Table 1. The participants were not on medication, had no vision problems, and did not suffer from chronic pain of forearm, shoulder and/or hand. The participants received a small monetary reward for participation. The local institution’s ethical committee approved the study. The participants were naive to the purpose of the experiment. They were fully informed after its completion.

1-2 Apparatus and stimuli
Apparatus and stimuli were the same as per Experiment 1, but for time intervals between the response and the subsequent stimulus (RSI). Initially, 1100 ms intervals were used that were gradually shortened to 100 ms in the final practice blocks (i.e., in Experiment 1 the RSI was 100 ms throughout practice). Thus RSI was 1100 ms in block 1 to 5, 900 ms in block 6 to 10, 700 ms in blocks 11 to 15, 500 ms in blocks 16 to 20 and 300 ms in blocks 21 to 25 during session 1, 700 ms in blocks 26 to 30, 500 ms in blocks 31 to 35, 300 ms in blocks 36 to 40, 200 ms in blocks 41 to 45 and 100 ms in blocks 46 to 50 during the second practice session. One further discrepancy with Experiment 1 is that 53 (rather than 32) pitch tones were generated for each block of 80 stimuli in the transfer to secondary task condition.

1-3 Procedure and design
The procedure was the same as for the instruction groups in Experiment 1. Hence, the participants were fully informed about the details of the ordered sequence of stimulus locations of the ASRTT and were required to learn the sequence by heart at the beginning of the first session. The details of the
sequence were reiterated at the beginning of the second session. As in Experiment 1, the participants were also encouraged to use this knowledge by awarding a grant of 15 Euro for best performance. The participants were informed about the increasing temporal difficulty during practice.

The design was similar to Experiment 1, except that the test phase did not include the fatigue protocol. Thus, after the 50th practice block (i.e., 10 epochs of five blocks), the test session included two retention tests interspersed with a transfer to the secondary task. The RSI was 100ms. Finally, the amount of explicit knowledge accrued during practice was assessed by a recognition task, a sorting task and an interview. Finally, it must be noted that unlike Experiment 1, there were no no-instruction groups involved.

2- Results

2-1 Performance after practice: Learning

Figure 3 shows that throughout practice response times for the ordered stimuli were shorter than for the random stimuli. This difference in response time (ΔRT) gradually decreased with the shortening of the RSI. Although differences in response time for the two stimuli emerged in both the younger and older adults, the ΔRT appears smaller among the older participants.

To verify whether explicit learning in older adults benefitted from initially longer RSI during practice, we first compared the response accuracy and times in the final practice block and first retention block of the younger and older group (Fig4). Next, the response accuracy and times of the older adults of the current Experiment 2 (i.e., with initially long, but decreasing RSI) were compared with those of the older adults in the instruction group of Experiment 1 (i.e., with short RSI throughout practice).

Response accuracy Differences in response accuracy for the ordered and random stimuli were small and never exceeded 4%. The analysis of variance did not reveal any significant effects for ΔRA, F's < 0.6, p's > 0.44. Moreover, two-tailed t tests for both groups separately showed that ΔRAs did
not exceed 0 in the final practice and first retention blocks, \( t's < 1.69, p's > 0.05 \). Finally, \( \Delta RA \) did not differ between the older adult instruction group of Experiment 1 and the older adult group in the current Experiment, \( F's < 1.9, p's > 0.19 \).

**Figure 3:** Response time for young adults (a) and older adults (b) as a function of practice epoch (i.e., first epoch (E1), second epoch (E2) etc.) and stimulus type (i.e., random (.) and ordered (→)) in Experiment 2.

**Figure 4:** Response time for young adults (a) and older adults (b) as a function of block (i.e., final practice (FP), first retention (R1), secondary task (S), and second retention (R2) blocks) and stimulus type (i.e., random ( ) and ordered (n)) in Experiment 2. *\( p < 0.05 \).
Response time As shown in Figure 4, both groups showed shorter response times for ordered as compared to random stimuli. Yet, also with the initial prolonged and subsequently decreasing RSI during practice the difference was much more pronounced for the younger adults than for the older adults. Thus, the analysis of variance for ΔRT returned a significant effect of Age, F(1, 34) = 12.6, p < 0.05, η² = 0.16. One-sample t tests showed that for both groups ΔRTs in the two blocks were significantly larger than zero, t's > 2.20, p's < 0.05. Finally, the analysis of variance comparing the two older adult instruction groups of Experiments 1 and 2 did not reveal any differences in ΔRT, F's < 0.8, p > 0.38.

Explicit knowledge assessment For the recognition task, an independent t test on the percentage of ‘good hits’ showed that the percentage of good hits was higher for the young adults (i.e., 90%) than for the older adults (i.e., 69%), t(27) = 4.10, p < 0.01. The ‘good hit’ percentages significantly exceeded 50% chance level in both groups, t's > 5.00, p's < 0.01. The percentage of ‘I don't know’ responses was low (2% and 10% for the younger and older adults, respectively), but significantly higher in the older adults group, t(27) = 2.80, p < 0.05. Importantly, the initially high and gradually decreasing RSI during practice did not lead to a higher percentage of ‘good hits’ for the older adults in the current experiment compared to the older adults of the instruction group in Experiment 1, t(23)= 0.60, p > 0.05. The percentage of ‘I don’t know’ response was significantly higher in Experiment 2, t(23) = 2.27, p < 0.05. Finally, the interview pointed to another –perhaps- important finding of the present experiment: whereas the all young and seven older participants were able to correctly recall the entire sequence and stated that they were indeed able to recognize and use this knowledge during the ASRTT, the nine remaining older participants commented having had serious difficulties to recognize and use the knowledge about the ordered sequence of stimuli during the ASRTT (as did all the older participants in the instruction group of Experiment 1). The pattern
of responses during practice and retention of these two subgroups will be further explored below.

2-2 Stability of performance after learning: secondary task

To assess stability of performance after learning as a function of age, response accuracy and timing in the transfer to secondary task condition and the first retention tests were compared for the groups. Accordingly, we only report the main and interaction effects for Test.

Response accuracy

The analysis of variance did not reveal significant differences of Test for ΔRAs, \(F's < 0.7, p > 0.42\). Separate one-sample t tests for both groups showed that ΔRAs did not exceed 0 in the transfer test, \(t's < 0.19, p's > 0.05\). The ΔRA did not differ between the older adult instruction group of Experiment 1 and the older adult group in the current Experiment, \(F's < 0.5, p > 0.46\).

Response Time

Figure 4 shows that adverse effects of the concurrent secondary task appeared in both age groups. Accordingly, only the Test effect was found significant for ΔRT, \(F(1, 27) = 15.0, p < 0.01, \eta^2_p =0.36\), while the interaction with Age was not, \(F(1, 27) = 2.2, p = 0.15\). One-sample t tests showed that for the older adults, the ΔRT in the transfer to the secondary task condition did not exceed 0, \(t(15) = 0.16, p > 0.05\), whereas the young adults response times were still significantly faster for ordered stimuli than random stimuli, \(t(12) = 3.26, p < 0.01\). No differences were found between the two older instruction groups of Experiment 1 and 2, \(F's < 0.7, p > 0.41\).

Tone identification

No effect of Age was found for the percentage of correctly identified tones, \(t(27) = 0.57, p > 0.05\), indicating that younger adults (i.e., 61% correct) and older adults (i.e., 57%) were equally accurate in discriminating low and high tones. The older instruction group showed higher

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6 The comparison between the transfer to secondary task condition and the second retention test revealed an identical pattern of results. We only report the contrast between the transfer to secondary task condition and the preceding first retention test, because this allows for a direct comparison with Experiment 1.
score in tone identification (83%) in Experiment 1 than in Experiment 2, $t(23) = 4.76, p < 0.05$.

2-3 Older users and non-users
Following the interview, we classified the older adults either as ‘user’ (i.e., the participants who reported to have been capable of using the knowledge about the order of the stimuli, $n = 7$) or as ‘non-user’ (i.e., participants who reported having been unable to exploit the knowledge, $n = 9$). Figure 5 suggested superior performance during practice for the group of users.

![Figure 5: Response time for the ‘users’ (a) and ‘non-users’ (b) among the older adults in Experiment 2 as function of practice epoch (i.e., first epoch (E1), second epoch (E2) etc.) and stimulus type (i.e., random (.) and ordered (−−))](image)

Yet, analyses of variance comparing $\Delta RA$ and $\Delta RT$ in the final practice block and the first retention did not reveal significant effects for Group, $F’s < 2.3, p’s > 0.14$. To the contrary, one-sample $t$ tests showed that whereas the group of non-users exhibited significant $\Delta RTs$ for both the final practice block and the
first retention block, \( t' > 2.40, p' < 0.05 \), the \( \Delta RTs \) for the group of users did not significantly exceed zero, \( t' < 2.40, p' \geq 0.054 \) (Fig. 6). In addition, the assessment of explicit knowledge in the recognition task also failed to reveal a difference for the percentage of ‘good hits’ between the two groups, \( t(14) = 0.04, p > 0.05 \). In other words, the self-reported ability to use knowledge during practice did not result in superior performance and recognition when tested with short RSI.

Nonetheless, Figure 5 clearly points to more pronounced \( \Delta RT \) during practice for the group of users in comparison to the group of non-users (except for the final sets of five practice blocks or epochs). As per Experiment 1, the extended practice sessions allowed for an assessment of the evolution
of response accuracy and response times in terms of triplets (i.e., patterned, random consistent and random inconsistent triplets)(Fig. 7). The 2(Group) x 10(Epoch) x 3(Triplet) analyses of variance with repeated measure over the last two factors revealed a significant Group by Triplet interaction for response accuracy, \( F(2, 28) = 4.20, p < 0.05, \eta^2_p = 0.23 \), and a significant Group by Epoch by Triplet interaction for response time, \( F(2, 28) = 3.89, p < 0.001, \eta^2_p = 0.28 \). Post-hoc comparisons indicated that the group of users was more accurate and faster for patterned and random consistent triplets than for random inconsistent triplets, but -cruically- were also more accurate and faster for patterned than random consistent triplets. However, for response time this latter difference disappeared in the last two Epochs (i.e., practice blocks with RSI equal to or shorter than 200ms). In contrast, the participants of the non-user group, only were accurate and faster for the random consistent as compared to the random inconsistent triplets. In short, only the users seem to have developed sensitivity to the second-order sequence of stimuli, but this sensitivity dissolved for short RSI. The non-users did not demonstrate any sensitivity to the order they were informed about.

![Figure 7: Response time for the 'users' (a) and 'non-users' (b) among the older adults in Experiment 2 as function of practice (i.e., first epoch (E1), second epoch (E2) etc.) and triplet type (i.e., random consistent (.), pattern (—) and random inconsistent (..)).](image-url)
3- Discussion

In Experiment 2, we initially imposed the participants with less rigorous time constraints while practicing the ASRTT, but gradually made the task harder to perform. We hypothesized that this manipulation would promote recognition of the sequence during practice, allowing the older adults to actually use the knowledge they received regarding the sequence. However, this was not borne out by the data, at least when considering the older adults as a group. The younger adults still profited more from the instructions than did the older adults, as per Experiment 1. In addition, explicit learning in younger adults allowed for more flexibility in addressing the secondary task without a complete break down of performance (i.e., the response time for the ordered stimuli remained significantly shorter than for the random stimuli). The low success in identification rate relative to Experiment 1 can most likely be attributed to the higher frequency of the tones in Experiment 2. Nevertheless, it cannot be ruled out that younger adults chose to sacrifice the accuracy of the secondary task to maintain ASRTT performance, given the low tone discrimination rate. A single tone identification would have been needed to verify this claim. Importantly, however, it is clear that even though both age groups exhibited the same low tone discrimination rate, only the young adults were able to prevent a complete break down of ASRTT performance, indicating higher flexibility after learning in comparison to the older adults.

Learning of the present group of older adults was not superior to the older adults in Experiment 1. In fact, the performance on the recognition task was not significantly improved relative to Experiment 1 and even suggested less certainty about the sequence (i.e., an increase in the number of 'I don't know'-responses). Rünger (2012) has recently shown that correspondence in duration of the interval between response and stimulus (RSI) during practice and the recognition task eases pattern recognition in ASRTT. Accordingly, the increased uncertainty in the recognition task among the older adults in
Experiment 2 compared to Experiment 1 may be due to less familiarity with the 100ms RSI duration of the recognition task.

Yet, older adults often show large individual differences in motor and cognitive functioning (Cherry & Stadler, 1995; Christensen et al., 1994; Hultsch, MacDonald, & Dixon, 2002), and the present findings are no exception. That is, some of the participants in the older group did report being able to recognize and use the order in the sequence that they were informed about, while others did not. Perhaps, surprisingly, this difference was not borne out in performance after learning: in fact, in the retention test the response accuracy and times for ordered and random stimuli were the same for this group of participants. However, the triplet analysis for the practice phase demonstrated that participants who reported that they were capable of exploiting the knowledge about the sequence exhibited sequence-specific sensitivity, reminiscent of the younger instruction group in Experiment 1. This attests to the ability of these older participants to use the explicit knowledge about the sequence to enhance performance. Importantly, however, this breaks down under the more rigorous time constraints with duration of RSI shorter than 200ms (during practice as well as during retention). In sum, a large minority of the older adults seems capable of explicit learning, but only under relatively lenient time constraints. It is noticeable therefore that in many studies evaluating older adults’ learning on the ASRTT, RSI typically do not exceed 200ms (D. V. Howard & Howard, 2001).

The remaining older participants, who reported that they were unable to recognize and draw on the received information, only showed signs of sensitivity to the most frequent occurring combinations during practice, which is reminiscent of the older instruction group in Experiment 1. Moreover, the pattern of response times in the final block of practice and the retention test suggested that sequential learning had occurred. This probably reflects a subtle sensitivity to the most frequent triplet (rather than the
patterned triplet), pointing to incidental learning being maintained even under the more rigorous time constraints.

The fact that older adults in Experiment 2 were still capable of learning by using explicit knowledge is in line with predictions from the graded perspective (Cleeremans & Jiménez, 2002) that longer time intervals between response and the subsequent stimulus would yield enhanced learning, because it induces better quality representations (Cleeremans & Sarrazin, 2007; Gaillard, Destrebecqz, Michiels, & Cleeremans, 2009). Yet, to what degree these representations are sufficiently strong to enable flexible control over the responses in the context of a secondary task, as was observed among young adults, remains unanswered. That is, the time constraints were already too rigorous for the older participants to manage without a change in the task context, and hence, we cannot reliably interpret the stability of their ASRTT performance while performing a concurrent task. In sum, while it is clear that explicit learning in ASRTT is degraded with aging, it can, if task constraints permit, still be induced to levels comparable to young adults. Further research with larger sample sizes is needed to verify this assumption. In addition, the current study indicates that rigorous time constraints may prevent manifestation of sequential motor learning in older adults who intentionally exploited knowledge to practice the sequence. Interestingly, the same rigorous time constraints, however, still seem to allow older participants who were incapable to use of explicit knowledge during practice, to show indications of (incidental) learning.

**General discussion**

The two experiments provide further evidence that aging is accompanied with declines in the explicit learning of a sequential motor task. In line with Reber’s (1992) claim, vulnerability for age was found to be much smaller for implicit learning. In fact, Experiment 1 showed that implicit learning of the older adults was preserved relative to young adults, at least for the complexity level
of the present second order sequence. This been said, others did find that also implicit may be degraded during ageing (Curran, 1997; D. V. Howard et al., 2004; J. H. Howard & Howard, 1997; Rieckmann & Backman, 2009). Reasons for the discrepancy between the previous work and the current study may be the more complex sequences or the larger amount of practice in the foregoing studies. It must however be noted that the previous studies did not verify that explicit learning actually occurred, and hence do not allow drawing definitive conclusions with respect to the relative deterioration of implicit and explicit learning in older adults.

Importantly, we show that the decline of explicit learning with age is likely related to the time constraints of the task as well. Previous work has indicated decrements in working memory (e.g., Salthouse, 1990; Wingfield et al., 1988) such as the ability to chunk stimuli (e.g., Verwey, 2010) or to handle highly complex stimuli (e.g., J. H. Howard & Howard, 1997). Yet, our findings suggest that it is not only the decline of these cognitive abilities per se that disrupts the recognition and exploitation of the regularity in a sequence of stimuli, but it is their deterioration relative to time available to complete a task that hinders explicit learning. In this respect, however, a large variability exists among older adults, which needs to be understood in more detail (Withagen & Caljouw, 2011). The variability points toward individual differences in the speed at which the explicit processes can still function, resulting in representations of unequal distinctiveness and strength (see below). This may also be the reason that even though there is some evidence for explicit learning occurring among older adults, it did not confer as much flexibility as it does in young adults. That is, young adults obviously profited from explicit learning relative to implicit learning; it enabled them to manage changes in the task context (i.e., performing a concurrent secondary task). This is consistent with the conjectures of Cleeremans and Jiménez (2002) that explicit modes of learning result in more stable, distinctive and stronger representations that boost flexibility of control over performance. It seems
that among older adults, for those participants in Experiment 2 who demonstrated some ability to learn explicitly, the developed representations were not expressible below a certain minimum temporal threshold.

On a practical note, the findings suggest that learning among older workers in for instance assembly industry may benefit from explicit instructions, but only when they can incorporate this knowledge by practicing and working at a somewhat slower pace. On the other hand, it was found that implicit learning remained spared by aging and even expressed it self under time constraints that did not allow for explicit learning. Yet, it also seems that implicit learning remained too weak to deal with contextual changes. Consequently, if alterations in the task or its context are unlikely to occur, then an implicit learning mode may be more advantageous for older workers, especially when time constraints are rigorous.

Given that aging adversely affects explicit learning on the ASRTT, it is worthwhile to have a closer look at the explicit processes that are likely exploited to perform the task. In the ASRTT, the participants respond to familiar and unknown stimuli that are presented in alternation. Consequently, the task requires identifying a stimulus as part of the learned sequence of stimuli. This triggers the subsequent stimulus, but the associated response has to be delayed until after the random unfamiliar stimulus has been responded to. In other words, the ASRTT not only requires recognition of the ordered stimuli and its associated response, but also the conscious inhibition of the anticipated subsequent responses. This inhibition likely requires temporary suppression of the conscious goal-directed top-down process in favor of the stimulus-driven process that is likely involved when responding to the unfamiliar stimuli (Corbetta & Shulman, 2002). It is particularly these conscious goal-directed processes involved in inhibition that are thought to be liable to the adverse effects of aging (Deiber et al., 2010; Zanto, Hennigan, Ostberg, Clapp, & Gazzaley, 2010). For example, in an investigation by Potter and Grealy (2008) participants were asked to copy an experimenter making
left-right wiping movements with a sponge on a surface. In one condition, the participants had to inhibit copying and continue making left-right wiping movements when the experimenter shifted to making up-down wiping movements. Older adults made many more errors (e.g., inhibition failure, temporary stoppage of movement) than younger adults. Age-related differences in the number of errors did not occur in a second condition in which the participants had to continue copying when the experimenter changed the direction of the swiping movements. This may indicate that elderly people have more difficulties than young adults performing explicit goal-directed motor tasks (as in the inhibition condition) than performing stimulus-driven adaptive motor tasks (as in the continued copying condition). These findings may point to a slowing down of the top-down goal-direct processes that are responsible for response suppression, while the bottom-up stimulus-driven processes are relatively spared during aging. Using visual event-related potential recordings, Deiber et al. (2010) found a similar differential deterioration of attention allocation with age on a face recognition task. For the ASRTT, the degradation of this explicit goal-directed process, and hence the difficulty to delay the response associated with the next stimulus of the ordered sequence, may actually lead the older participants to (strategically) diminish its engagement in responding. The observation that reducing time constraints allowed some of the older participants in Experiment 2 to actually use their knowledge of the sequence underlines the hypothesis that age-related decline in explicit motor sequence learning reflects a selective slowing down of goal-directed attentional processes. In fact, this hypothesis would be easily reconciled with the conceptualizations of Cleeremans and Jiménez (2002, see also Jiménez & Vazquez, 2005), in which implicit and explicit learning are associated with a local (or stimulus-driven) bottom-up process and a global (goal-directed) top-down process respectively.
In conclusion, the current study underlines that for sequential motor tasks the adverse effects of aging are clearly more pronounced for explicit than for implicit learning, the latter being spared. It seems that the decline in explicit learning is related to working memory functioning, but not uniquely so. Altering the task-constraints (i.e., the time available to process and use task-specific knowledge during practice) can invoke higher levels of explicit learning.

Acknowledgements
The authors thank Lisa Knelange and Bianca Ruigrok for their help in carrying out Experiment 2.

Funding
This work was financially supported by Body@work, Research Center on Physical Activity, Work and Health.