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Verneau, M.M.N.

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Proactive and retroactive transfer of middle age adults in a sequential motor learning task

We assessed the effects of aging in the transfer of motor learning in a sequential manual assembly task that is representative for real working conditions. On two different days, young (18–30 years) and middle-aged adults (50–65 years) practiced to build two products that consisted of the same six components but which had to be assembled in a partly different order. Assembly accuracy and movement time during tests, which were performed before and after the practice sessions, were compared to determine proactive and retroactive transfer.

The results showed proactive facilitation (i.e., benefits from having learned the first product on learning the second one) in terms of an overall shortening of movement time in both age-groups. In addition, only the middle-aged adults were found to show sequence-specific proactive facilitation, in which the shortening of movement time was limited to components that had the same order in the two products. Most likely, however, the sequence-specific transfer was an epiphenomenon of the comparatively low rate of learning among the middle-aged adults. The results, however, did reveal genuine differences between the groups for retroactive transfer (i.e., effects from learning the second product on performance of the first). Middle-aged adults tended to show more pronounced retroactive interference in terms of a general decrease in accuracy, while younger adults showed sequence-specific retroactive facilitation (i.e., shortening of movement times for components that had the same order in the two products), but only when they were fully accurate. Together this suggests that in the learning of sequential motor tasks the effects of age are more marked for retroactive transfer than for proactive transfer.
1- Introduction

Aging adversely affects motor performance and learning. Elderly people not only act more slowly, deliberately and, occasionally, less accurate but also do require greater efforts to achieve enduring improvements in motor performance. The sometimes problematic loss of motor efficacy in late adulthood stands out the most, but the very first signs of a decline in motor learning may already arise at the age of 40 years in middle adulthood (Perrot & Bertsch, 2007; Voelcker-Rehage, 2008; Voelcker-Rehage & Willimczik, 2006). At the age of 60 years or beyond, however, the decline in learning becomes much more ubiquitous, as for instance has been shown for sequential motor learning (Seidler, 2006; Shea, Park, & Braden, 2006). Many have pointed to the weakening of executive function as major determinant of the age-related decline in motor learning (Craik & Bialystok, 2006; Zelazo, Craik, & Booth, 2004). As a point in case, the gains in motor performance after explicit motor learning, which strongly relies on the conscious processing of declarative information in working memory, are often less well retained than the performances increases following implicit learning (Chauvel et al., 2012; Ren, Wu, Chan, & Yan, 2013; Steenbergen, van der Kamp, Verneau, Jongbloed-Pereboom, & Masters, 2010).

An issue in motor learning that has relatively been overlooked is whether, except for the rate of learning, aging also affects the transfer of learning. In other words, how the learning of one motor action affects the performance and learning of a similar but not identical second action. Indeed, across the life span, motor performance often needs to be modified or re-learned when circumstances demand. It is not uncommon, for example, that workers after having learned to assemble a product from various components, have to learn to build a second product out of the same components in a (partly) different order or with one component replaced. Particularly, age-related changes in motor learning must also be evaluated in terms of the degree to which it facilitates or hinders subsequent performance
and learning of slightly different actions. Accordingly, the current study compares the transfer of sequential learning by young and older adults in a representative manual assembly task, in which a product is built by gathering six components in a fixed sequence.

The motor learning literature typically distinguishes proactive and retroactive transfer. Proactive transfer occurs when learning a new motor action influences the performance or learning of a similar action in the future. Retroactive transfer occurs when learning a new motor action impacts the performance of a previously learned action (Blank, 2005; Hanseeuw, Seron, & Ivanoiu, 2012). These transfers can either be beneficial (i.e., facilitation) or detrimental (i.e., interference). In the case of sequential motor learning, as in the current manual assembly task, transfer can occur on at least two levels. First, transfer can appear as a general accommodation to the task constraints, which would for instance be reflected in an overall speeding up of movement execution. For instance, Seidler (2007) had young and older adults practice a series of joystick movements to targets at different orientations. Half of the participants practiced successive blocks in which they moved toward 30°, 15°, and 45° targets, respectively, while the other half practiced successive blocks toward 45°, 15°, and 30° targets. Proactive facilitation was present for accuracy in the target orientation block that was practiced last (i.e., 45° in one group and 30° in the other) regardless of the age-group. Yet since motor learning did not involve a sequence of movements, transfer reflects general accommodation only; with single movements, no sequence-specific transfer can occur. Transfer that is specific to the order of the learned sequence is the second level at which transfer can occur. In this case the speeding up (or slowing down) is restricted to movements within the sequences that are performed in the exact same order but does not encompass movements within the sequences that have a different order. Such transfers have been investigated in a series of studies. Indeed, Panzer and colleagues examined proactive and retroactive transfer in young adults who learnt a 16-target
movement sequence on one day, followed by practice of a similar sequence but with two targets altered on the second day (Panzer & Shea, 2008; Panzer, Wilde, & Shea, 2006). It was found that practice on the first sequence did not benefit learning of the second sequence (i.e., no proactive facilitation), while practice of the second sequence degraded performance of the first sequence (i.e., retroactive interference) (Panzer et al., 2006). Prolonging practice of the first sequence, however, resulted in proactive facilitation becoming stronger, while retroactive interference reduced or even disappeared (Panzer & Shea, 2008). Panzer et al. argued that transfer is related to the relative stability of the memory representations of the two sequences; the sequence with the stronger representation impacts the other. Thus, when the first sequence is strengthened by longer practice, proactive facilitation is increased and retroactive interference is reduced.

Executive functions are crucial to manipulating, storing, and retrieving of movement sequences and are thus at stake in the transfer of motor learning. Yet it is these functions that are often degraded among older adults (Salthouse, 1990). In addition, it has been reported that older adults are less apt to efficiently combine different discrete movements into one smooth sequential motor action (Shea et al. 2006; Verwey, 2010; Yan, 2000). Transfer after sequential motor learning has not been studied in older adults, but the less efficient merging of discrete movements into one sequence, and the resulting weak memory representation of the movements sequence, may on the one hand jeopardize older adults’ ability to profit from proactive transfer and on the other hand increase the likelihood of retroactive interference.

Previous work did investigate the transfer of learning in older adults for cognitive tasks, such as recalling different lists of words. This pointed to reduced proactive and retroactive transfer in older adults. For example, when learning a second list of words, older adults show increased intrusion of words from the originally memorized list (Hasher, Chung, May, & Foong,
In addition, older adults have been shown to be more vulnerable for retroactive interference than younger adults (Hedden & Park, 2001). The increased interference with aging is explained by a weakening of inhibition, making it more difficult for older adults to eliminate previously memorized words when recalling a list. It has been proposed that interferences during motor transfer were a biased motor behavior due to the earlier learned motor task (Walter & Swinnen, 1994). In case of sequential motor learning, the weakening of inhibition processes could make older adults more prone to interference. This contrasts to the hypothesis that learning in older adults results in weaker representations that are easily overwritten. However, the cognitive load in these exclusively cognitive tasks is much higher and probably unrepresentative of the cognitive demands in motor actions, raising the issue to what degree these findings can be generalized to sequential motor learning.

In sum, the current study investigates the effect of age on proactive and retroactive transfer in the learning of sequential manual assembly task. We focused on middle-aged adults between 50 and 65 years old because this age-group is part of the workforce in the manual assembly industry, where the ability to efficiently and flexibly learn motor actions is an important requirement. Accordingly, the task was chosen as representative as possible for a worker in the assembly industry and involved assembling a product out of components that need to be combined in a fixed order, and hence, require a fixed sequence of successive movements. Participants learned to build two similar products, with half the components being assembled in the same order. It was expected that compared to the young adults, middle-aged adults’ less efficient ability to blend single discrete movements into one smooth sequence during practice would result in weaker memory representations (i.e., the amount of practice was the same for both groups). Consequently, we anticipated reduced proactive facilitation and increased retroactive interference for sequence-specific learning (i.e., for the sequences that were
the same across the two products) for middle-aged adults compared to young adults. However, a general speeding up was expected for both age groups (i.e., proactive and retroactive facilitation).

2- Methods

2-1 Participants

Nineteen young adults between 18 and 30 years of age (mean age = 22.5, SD = 3.5 years) and eighteen middle-aged adults between 50 and 65 years of age (mean age = 58, SD = 4.5 years) participated in the study. All participants were self-proclaimed right-handers, had normal or corrected to normal vision, and reported that they did not suffer from chronic pain of the right forearm, shoulder, and/or hand. They received a small monetary reward for participation. The participants provided written informed consent before the study but were kept naive to the purpose of the experiment until after completion of the study when they were fully debriefed. The local institution’s ethical committee approved the study.

2-2 Apparatus and stimuli

The gross assembly task of the ATA®-workstation (Assembling Task Apparatus, Top Productivity, The Netherlands, see Fig. 1A) was used (for a full description, see Verneau et al., 2014). This workstation is developed to evaluate workers’ capability for performing different types of assembly tasks (e.g., gross and fine assembly, sorting, etc.). It creates an environment to autonomously learn (i.e., without an instructor) to construct a product by sequentially assembling (i.e., reach, grasp, orient and place) six components in a fixed order. Through the dedicated PG-viewer software, the workstation monitors the worker’s actions and directs him or her through the assembly task in a step-by-step fashion. For the current study, the workstation had a series of six bins, each of which was filled with one component. The bins were positioned directly behind the workspace where the product was to be built. Each bin was equipped with a movement sensor that registered when the worker’s hand entered the bin; a light bulb above the bin indicated from
which bin the next component was to be picked. Above the row of bins stood a
monitor that displayed pictorial and text instructions. Finally, a green
command button was placed to the right of the workspace. Workers had to
press the command button after having placed a component. The workstation
would then signal the next component.

The product was assembled around a long iron stick (13 cm in length
and 1.2 cm in diameter) at which four rings of different color, shape, and size
(i.e., black 1.7 cm in diameter, blue 2.5 cm, white 3 cm, and red 2.1 cm) had to
be placed in a prescribed order (see Fig 1D). To finish the product, a black cap
(1.3 cm) was placed on top of the stick. Hence, for each product, the stick was
always the first component to be grasped, while the last was the cap. To ease
construction, the workspace contained a hole (10 cm above its front edge) in
which the stick had to be placed. Once a product was constructed, it was
placed into a carrier (positioned behind the hole) that stocked 12 products.

An Optotrak Certus Motion Capture System (Northern Digital Inc.)
was used to record the movement of the participant’s right hand with a
sample frequency of 100Hz. The camera was placed horizontally, at a height
of 1.8 m to the left side of the workstation. Prior to the experiment, the
positions of 6 IREDs placed at known locations between the 6 bins and near
the command button were recorded and served as a frame of reference for
subsequent analyses. During the experiment, two IREDs were attached to the
participant’s right hand (i.e., the metacarpophalangeal joint of the thumb and
on the wrist at the base of the anatomical snuffbox). The positions of the two
IREDs were continuously recorded throughout the experiment. Finally, to
assess working memory function, the Digital Memory Span test from the
WAIS-iii was used, which assesses the ability to recall and manipulate
sequences of numbers.

15 The current study was part of a larger study (see Verneau et al., 2014) in which the instructions
were systematically varied. For half of the participants, the instructions were general, while for
the other half instructions were more detailed through the assembly process. Preliminary
analyses showed that the different types of instruction did not affect proactive and retroactive
transfers. Hence, the effects of instructions are not taken into account here.
Figure 1: (A) The ATA workstation with a participant reaching for a bin to pick a component. (B) Flow diagram of the experiment. Note: Sessions 1 and 2 were separated for at least 24 hours with a maximum of 4 days. (C) Schematic representation of the hand’s trajectory in the working station from above. The hand’s path starts once the stick is placed in the hole until all components are assembled. (D) Product 1 and Product 2. Both products are composed of 4 pairs of components. Pairs 1 and 3 are present in both products (i.e., Same pairs) while pairs 2 and 4 are not (i.e., Different pairs).

2-3 Procedure and Design

Participants performed the assembly task while standing at the workstation. They were required to use their right hand to pick and place the components. The height of the counter (i.e., workspace with the bins) was adjusted to each participant length, while the monitor was matched to eye height. The experiment consisted of two sessions that were separated for at least 24 h with a maximum of 4 days (mean young adults = 2.0, SD = 1.0, mean middle-aged adults = 2.0, SD = 1.0, $F(1, 35) = 0.51$, ns). The first session started with the completion of the Digital Memory Span test of the WAIS-iii. This was
followed with instructions about the workstation, its use, and the assembly task. Participants then started the practice phase. During the practice phase, they repetitively assembled the six components into one product in the order specified by the workstation (Product 1). Specifically, participants first pressed the green command button to trigger the instruction regarding which bin to pick the component from; they then picked the component, placed it (i.e., the stick into the work table’s hole, the other components over the stick), and pressed the green command button again to trigger the next instruction and so on for the next five components. After the sixth component (i.e., the cap) was placed, the product was finished and the participants had to place it in a carrier and then press the command key to start assembling the next product. Once the carrier was full (i.e., 12 products), the experimenter removed it from the workspace and placed a new one. If the participant took the wrong component (i.e., the movement sensor of the wrong bin was activated), a buzzer generated an error tone and instructions remained until the correct component was taken (i.e., the correct movement sensor was activated). Consequently, during practice, it was not possible to assemble an incorrect product. In total 10 blocks of 12 products (i.e., \( 72 \times 10 = 720 \) components) were completed during the practice phase. This took approximately 1 h, including a 2-min break between each block and a 5-min break after the completion of the fifth block.

Because instructions on each practice trial would likely lead to the participant’s performance becoming strongly dependent on the information conveyed in the instruction, also after practice, a fading procedure was used in which the frequency of instructions gradually decreased during practice (Wulf, Schmidt, & Deubel, 1993). Accordingly during practice, in blocks 1 and 2, instructions were provided for each of six components: in blocks 3 and 4, for the five first components and so on. Consequently, blocks 9 and 10 only conveyed information for grasping the first two components.
Five minutes after the practice phase, the first test block (i.e., Test 1) for Product 1 started. During this and the remaining test blocks, the workstation did not provide any instructions. For Test 1, participants were asked to assemble twelve exemplars of Product 1. This completed the first session at Day 1. During the second session at Day 2, participants first performed a second test block (i.e., Test 2) of 12 exemplars for Product 1. The procedure for Test 2 was identical to Test 1. Subsequently, participants received a new set of instructions regarding the sequence in which components for the second product (i.e., Product 2) had to be assembled. Compared to Product 1, in Product 2, two pairs of successive components (Pair 1 and 3) were interchanged (see Figure 1B). Practice also consisted of 10 blocks of 12 twelve products and was followed by a test block (i.e., Test 3) of 12 exemplars for Product 2. Finally, after a 5 min-break, participants performed a final test block (i.e., Test 4) of 12 exemplars of Product 1. Similar to all other tests, no additional information or clues regarding Product 1 was provided (for a schematic representation of the design, see Fig. 1B).

2-4 Data analysis
The performance was measured by accuracy and movement time. The evolution of the averaged time needed to assemble one product in each block (i.e., movement time) was monitored throughout the practice and test phases of the experiment. The accuracy was only determined for the four tests blocks (i.e., no incorrect product could be assembled during the practice). We calculated the percentage of correctly assembled products for each of four test blocks Test 1 to Test 4. To determine movement times, the kinematic recordings were filtered with a fourth order low-pass Butterworth filter with a cutoff frequency of 1.7. This cutoff frequency was based on spectral analysis. The beginning of the assembly movement of each product was defined as the
moment the hand left the stick (after placing it in the hole\textsuperscript{16}) and the end as the moment the cap was placed over the stick. The position data of the hand IREDs and the six reference IREDs placed at known locations between the bins and near the command button were used to determine the moments the hand approached and moved away from the stick (see Fig 1C). The onset of the movement occurred between after the stick was placed between and the hand approached the command button. Specifically, within this time interval, movement onset was defined when the hand IRED’ was still within 16.5 cm of the hole and its lateral speed (consistently) turned negative (i.e., moved toward the right in the direction of the command button). The movement offset was calculated in a similar manner after the cap was placed. The movement time (MT) was calculated by taking the difference between the onset and the offset for each assembled product and averaged for the twelve products within one block. Outliers in MT were removed following the outlier labeling method of Hoaglin (Hoaglin & Iglewicz, 1987; Hoaglin, Iglewicz, & Tukey, 1986), in which outliers are defined relative to lower and upper bounds for percentiles scores (i.e., lower bound = P25 - ((P75 - P25) * 2.2) and upper bound = P75 + ((P75 - P25) * 2.2). The time needed to grab and place each individual component was also determined for each product.

To assess differences between groups and tests, our general approach was to use 2(Age: young adults, middle-aged adults) × 4 (Test: Test 1, Test 2, Test 3, Test 4) ANOVA with repeated measures on the last factor. When appropriate, for these and subsequent ANOVAs, Huyn-Feldt p-values were considered to accommodate violations of the sphericity assumption. Post hoc comparisons were performed using t tests with Bonferroni corrections (α = 0.05). Bonferroni corrections were also applied whenever a series of t test was conducted. Partial eta-square (ηp\textsuperscript{2}) values were reported to determine

\textsuperscript{16} Due to technical problems, the workstation did not always detect the grasping of the stick (i.e., the first component), requiring the participants to re-enter the bin, which prolonged movement time for this component. Hence, we excluded the first component from our analyses.
the proportion of total variability attributable to each factor or combination of factors.

3- Results

Figs. 2B and 2C show performance accuracy and movement times during each of the four different tests for both the younger and middle-aged adults. The ANOVA for accuracy revealed a significant main effect of Test, $F(3, 105) = 22.4$, $p < 0.001$, $\eta^2 = 0.39$. However, neither the main effect of Age ($F(1,35) = 3.53$, $p > 0.05$), nor the Age × Test interaction ($F(3,105) = 3.87$, $p = 0.056$) was found significant, albeit showing that the middle-aged adults tended to perform less accurate on Test 4. The ANOVA for movement time showed significant effects for Test, $F(3, 105) = 8.04$, $p < 0.001$, $\eta^2 = 0.19$; Age, $F(1, 35) = 51.2$, $p < 0.001$, $\eta^2 = 0.59$; and Age × Test interaction, $F(3, 105) = 4.02$, $p < 0.05$, $\eta^2 = 0.10$. Follow-up analyses were carried out to specifically assess proactive and retroactive transfer. Proactive transfer was studied by post hoc comparing Test 1 (i.e., performance for Product 1 immediately after practicing it) to Test 3 (i.e., performance for Product 2 immediately after practicing it), while retroactive transfer was studied by post hoc comparing Test 2 (i.e., performance for Product 1 just before practicing Product 2) to Test 4 (i.e., performance for Product 1 immediately after practicing Product 2). With respect to retroactive transfer, researchers have often compared the equivalents of Test 1 to Test 4. This, however, might exaggerate retroactive transfer, because it presumes an improbable 100% consolidation in performance from Day 1 to Day 2. Hence, to examine retroactive transfer, Test 4 was compared to Test 2. The results of these follow up analyses are presented below in separate sections. We used Bonferroni corrections for multiple comparisons, where appropriate.

3-1 Proactive transfer

3-1-1 Accuracy: Figure 2B shows a consistently high level of accuracy in Tests 1 and 3 for both groups. Accordingly, post hoc analysis did not indicate a
difference in accuracy between the two tests, suggesting that no proactive transfer occurred (p > 0.05).

Figure 2: (A) Movement times during practice. Movement times for assembling a product for young and middle-aged adults as a function of Block. (B) Accuracy during Tests. Percentage of correctly assembled products for young and middle-aged adults as a function of Test. * p < 0.05. (C) Movement times during Tests. Movement times for assembling a product for young and middle-aged adults as a function of Test. * p < 0.05.

3-1-2 Movement time (MT): Figure 2C suggests that the middle-aged adults, but not the younger adults, had shortened movement times in Test 3 compared to Test 1. Indeed, post hoc analyses only confirmed differences between the two tests for the middle-aged adults, thus suggesting that middle-aged participants benefitted from proactive facilitation (p < 0.05). To examine whether this facilitation entailed sequence-specific learning or reflected a general speeding up (i.e., overall accommodation), we compared the percentages of shortening of movement time (i.e., $(\text{MT}_{\text{Test3}} - \text{MT}_{\text{Test1}})/\text{MT}_{\text{Test1}} \times 100$) for pairs of successive components that had the same
order across Products 1 and 2 (i.e., Same pairs) to that of pairs that consisted of components in a different order (i.e., Different pairs). That is, Product 1 and Product 2 have pairs that share successive components, while other pairs are unique for either Product 1 or Product 2 (see Fig. 1D). Sequence-specific learning would occur if shortening of movement time is larger for Same pairs than for Different pairs. A 2(Age: young adults, middle-aged adults) × 2(Pair: Same, Different) ANOVA with repeated measures on the last factor over shortening of movement time showed an effect of Pair with moderate effect size that just failed to reach significance, \(F(1, 35) = 4.07, p = 0.051\), suggesting a greater shortening of movement time for Same pairs (i.e., \(M = 2.8\%\), \(SD = 0.84\)) than for Different pairs (i.e., \(M = 1.3\%\), \(SD = 1.16\)). One-sample \(t\) tests additionally showed that the shortening in movement time significantly exceeded zero for Same pairs, but only among the middle-aged adults, \(t(17) = 2.75, p < 0.05\). The shortening in movement time was not significant for Different pairs (\(t's < 1.32, p's > 0.05\)). Together, this provides support for sequence-specific proactive facilitation among middle-aged adults but not for young adults.

3-1-3 Movement times during practice: We also assessed proactive transfer by comparing performance levels for both products early in practice. Proactive facilitation would be indicated if in corresponding practice blocks performance for Product 2 is superior to performance for Product 1. Indeed, Figure 2A illustrates that movement time in the first Practice Block for Product 2 is clearly reduced relative to movement time in the first Practice Block for Product 1. A series of paired \(t\) tests comparing movement time in the first Practice Block for Product 2 to movement times in Practice Blocks 1, 2, etc., for Product 1 showed that for the younger adults, initial movement time for Product 2 was shorter than movement times for Product 1 in Practice Blocks 1 to 3, \(t's(18) > 2.84, p's < 0.01\), whereas in the middle-aged adults initial movement time for Product 2 was only shorter compared to movement times for Product 1 in Practice Blocks 1 and 2, \(t(17) > 4.30, p's < 0.001\). This
shows that proactive facilitation occurred in both groups but was somewhat greater among younger adults. To assess whether facilitation was sequence-specific or reflected a general speeding up, we compared the shortening of movement times for Same and Different pairs of Products 1 and 2 for Practice Block 1 by using a 2(Age: young adults, middle-aged adults) × 2(Pair: Same, Different) ANOVA with repeated measures on the last factor. This only revealed a significant main effect of Age, $F(1, 35) = 4.31$, $p < 0.05$, $\eta^2 = 0.11$, indicating that the younger adults had larger shortening in movement time (i.e., $M = 30.0\%$, $SD = 2.5$) than middle-aged adults (i.e., $M = 22.0\%$, $SD = 2.6$). However, no effects of Pair were found ($F(1,35)= 1.99$, $p > 0.05$). Finally, one-sample $t$ tests showed that shortening of movement time for both the Same and Different pairs were significantly larger than zero for the young adults as well as for the middle-aged adults, $t's > 11.7$, $p's < 0.001$. Together this indicates clear proactive facilitation during practice that is general rather than sequence specific for both age-groups, but stronger among the young adults.

3-2 Retroactive transfer

3-2-1 Accuracy: There was a dramatic drop in accuracy from Tests 2 to 4 in assembling Product 1 (see Fig. 2B). Indeed, post hoc comparisons confirmed that both groups were less accurate in Test 4 than in Test 2 ($p < 0.05$). Hence, for both the young and the middle-aged adults, the learning of Product 2 degraded performance on Product 1, a clear example of retroactive interference. However, perusal of the individual data suggested (as did the nearly significant Age × Test interaction, see above) that interference did not occur in all participants but was restricted to 6 young adults and 11 middle-aged adults, interference being defined as making at least one incorrect product. In Test 4, four types of pairs of successive components can be identified for Product 1 relative to Product 2 assembled in Test 2: pairs of successive components that are the same in Product 1 and 2 (i.e., Same pairs); pairs of successive components that are specific to Product 1 (i.e., Specific pairs); pairs of successive components that are specific to Product 2 and
intruded in Product 1 (i.e., Intrusion pairs); and pairs of successive components that do not belong to either product (i.e., New pairs). We reasoned that sequence-specific retroactive interference would be indicated if the frequency of Intrusion pairs in wrongly assembled products of Test 4 significantly exceeds the 10% chance level (i.e., two out of a total of 20 theoretical possible pairs that do not belong to Product 1 are Intrusion pairs). One-sample t tests for each age-group however showed that neither the percentage of Intrusion pairs in the young adults (M =15.8%) nor the percentage of Intrusion pairs in the middle-aged adults (M= 11.4%) exceeded chance, t's< 1.44, p > 0.05. Thus, retroactive interference was not sequence-specific. It thus appears that participants merely forgot the sequence of components for Product 1 rather than building successive components (pairs) from Product 2 into Product 1.

3-2-2 Movement Time: As suggested by Figure 2C, post hoc comparisons did not indicate differences in movement time between Tests 2 and 4 (p's > 0.05). However, this analysis includes participants that assembled the components in the wrong sequence. Hence, we restricted the investigation retroactive transfer to participants that assembled all twelve products correctly. This was done by first comparing the percentage of shortening in movement times from Test 2 and Test 4. The large difference in sample size (i.e., 13 young and 7 middle-aged adults) did not allow us to conduct an Age × Test ANOVA. Instead, within each age-group, paired t-tests comparing the assembly time of Test 2 and Test 4 were performed. It showed that the young participants gained speed in assembling Product 1 in Test 4 compared to Test 2, t(12) = 2.81, p < 0.05; however, the middle-aged adults did not, t(6) = 1.13 , p >0.05. Additional one-sample t-tests against zero for the younger group revealed enhanced speed for both pairs in Test 4, t's > 2.3, p's < 0.05, with the gain for Same pairs (i.e., 7%) being significantly greater than for Different pairs (5%) t(12)= 2.9, p < 0.05 , suggesting that retroactive facilitation was general as well as sequence specific among the young participants. Among the middle-
aged adults, the speed did not increase in Test 4, $t(6) = 1.1$, $p > 0.05$, neither the gain for Similar pairs (1.8%) nor for Different pairs (3.5%) exceeded zero, $t's < 1.36$, $p's > 0.05$.

3-3 Digital memory span

Regarding the working memory function, scores of the Digital Memory Span test of the WAIS-iii between age-groups were analyzed with a univariate ANOVA. There was no significant difference between the two groups (mean young adults = 19.0, SD = 4.0, mean middle-aged adults = 17.0, SD = 3.0, $F(1,35) = 2.54$, $p > 0.05$).

4- Discussion

We investigated the proactive transfer and the retroactive transfer of learning in a complex sequential motor learning task among middle-aged adults between 50 and 65 years of age. We purposely used an assembly task on a commercially available working station so that performances are representative for the working conditions that middle-aged adults may encounter. We hypothesized the reduced transfer of learning among middle-aged participants because with aging the same amount of practice typically results in weaker memory representations. The findings for proactive transfer will be discussed first, followed by retroactive transfer.

4-1 Proactive transfer

There was clear evidence for proactive facilitation, but this was limited to movement time. Indeed, the product was already correctly assembled after the first day of practice, and hence, further improvements in accuracy were impossible on the second day. With respect to movement time, however, proactive facilitation occurred for both age-groups; during the early practice blocks of Product 2, participants were much faster than during the first practice blocks of Product 1. This facilitation, however, was somewhat greater for the younger participants. Notably, this benefit was not sequence-specific because the gains in movement speed were equal for pairs that were the same and different between the two products, indicating that the proactive
facilitation early during practice of Product 2 was largely due to a general speeding up. This was true for both age-groups, although less so for the middle-aged adults. The later can likely be attributed to the widely reported reduced rate of (motor) learning in older adults (Bleecker, Bollawilson, & Heller, 1985; Etnier, Romero, & Traustadottir, 2001; Raz, Williamson, Gunning-Dixon, Head, & Acker, 2000; Rodrigue, Kennedy, & Raz, 2005; Schwerha, Wiker, & Jaraiedi, 2007).

More importantly, performance after practice (i.e., during the test phase) showed proactive transfer among middle-aged adults, but not among young adults. This proactive facilitation in the middle-aged group was exclusively related to sequence-specific gains in speed (i.e., gains were largest for pairs of components that were the same for both products). Possibly, the absence of this facilitation in younger adults is due to a ceiling effect. They may have been so fast for Product1 that further increases in speed were more difficult to achieve. Also Panzer et al. (2006) did not find proactive transfer after equivalent amounts of practice of two motor sequences in young adults. The middle-aged adults, on the other hand, did not yet perform at optimal speed after practicing Product 1, and hence, practice of Product 2 led to further improvements for the pairs of components that were assembled in the same order as in Product 1. Taken together, it seems that the occurrence of proactive transfer is related to how far learning has advanced. The further participants have progressed on the learning curve, the less likely it is that additional gains due to proactive facilitation arise. In the present study, the middle-aged adults showed lower rates of learning than younger adults, and hence, they benefitted more from proactive transfer after learning. If correct, then proactive transfer may not be affected by age per se but is a function of the degree of learning instead. In other words, despite a slower rate of sequential motor learning, middle-aged adults are capable of benefitting from earlier learned combinations (Verwey, 2010; Verwey, Abrahamse, Ruitenber, Jimenez, & de Kleine, 2011).
4-2 Retroactive transfer

In contrast to proactive transfer, the retroactive transfer observed in the current study adversely affected assembly performance in both age-groups, corroborating previous reports (Panzer et al., 2006). A dramatic drop in accuracy occurred for assembling Product 1 after having practiced Product 2. This retroactive interference tended to be more prevalent among the middle-aged adults, although this effect just failed to reach significance. The interference appeared mainly as a matter of forgetting or confusion, since there was no clear evidence that pairs of components of Product 2 intruded into the assembly of Product 2. Hence, we do not find evidence for a weakening of inhibition as a cause for enhanced retroactive interference in middle-aged adults, as was found for the learning of cognitive tasks (Hedden & Park, 2001). Also, Panzer et al. (2006) did report that retroactive interference was sequence-specific rather than general. This was reflected by greater movement duration for non-common than common pairs during recall. By contrast, in the current study retroactive interference was only apparent in performance accuracy and not in movement time. This discrepancy with the current study may be due to the current study not imposing the correct motor sequence in the test phase, while Panzer et al. did. Without cueing, approximately half of the participants in the present study were simply unable to recall the correct sequence, particularly among the middle-aged participants. Thus, in former studies, the cueing might have helped reveal sequence-specific interferences in movement time that do not occur in the case of freely generated movement.

In addition, when considering only the participants that did successfully assemble Product 1 after having practiced Product 2, it was found that the young participants did benefit from retroactive transfer with respect to movement time. The middle-aged participants did not demonstrate any transfer. Hence, retroactive facilitation for movement speed seemed to decline
with age. Moreover, the retroactive facilitation among the young adults was both sequence-specific and general.

It is not particularly clear why the middle-aged adults were not able to profit from learning a second product, also because they are less likely than the young adults to have reached optimum assembly speed already. Possibly, the recall of the correct sequence in itself may have been more effortful, preventing increases in movement speed. That is, the retrieval of the correct sequence relies on episodic memory, which has repeatedly been shown to slow down with age (Beaunieux, Hubert, Pitel, Desgranges, & Eustache, 2009; Hoyer & Verhaeghen, 2006a, 2006b). This being said, we did not find differences in working memory capacity between the two groups. Hence, it is important for future research to further verify relationships between these cognitive functions and retroactive transfer, and also to pinpoint the individual differences within age-groups.

4-3 Conclusions

In sum, proactive transfer was larger among middle-aged adults, but this was likely due to a slower rate of learning than in young adults. By contrast, there seem to be genuine age-related differences in retroactive transfer with interference appearing larger among middle-aged adults (i.e., accuracy) and facilitation being larger among young adults (i.e., movement speed).

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