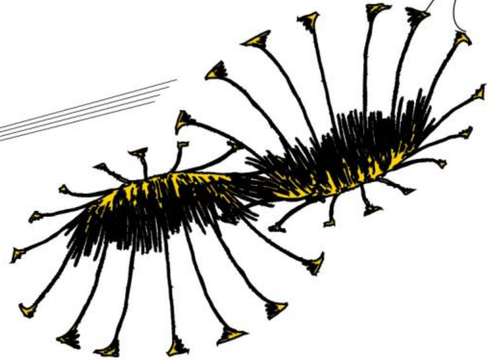
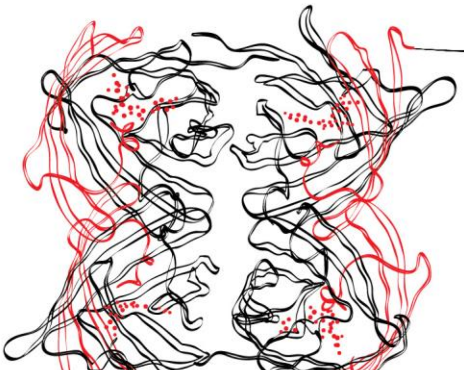
MOTOR SEQUENCE LEARNING: HOW AGEING INFLUENCES THE DEVELOPMENT OF MOTOR SKILLS





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Abstract

This study examined how ageing influences the capacity to develop new motor skills over time. This was done by using a Discrete Sequence Production (DSP) task consisting of a three-key and a six-key sequence. The participants could be divided into a young adult group (18-23) and a group of elderly (74-85). They participated for two consecutive days. Both days consisted of a nine block practice phase. On the second day after the practice blocks, the participants executed a test block consisting of a sub-block containing the familiar sequences and a sub-block of new three-key and six-key sequences. Furthermore, the participants executed a digit-symbol substitution task and a visuospatial working memory task to study respectively processing speed and working memory. The results demonstrate that elderly were substantially slower when executing the DSP task for both the unfamiliar and familiar sequences. The use of motor chunks was weaker for the elderly in comparison to the young adults, but they still had a positive chunking index indicating that the elderly do make use of chunking mode. Analyses also showed that the elderly in particular profit from an extended practice phase. Throughout time, the increase of chunking index of the young adults stagnated, whereas the elderly their chunking index was still developing. No effects were found of the condition of processing speed and working memory on the development of motor skills.

Abstract

In dit onderzoek is er gekeken naar hoe veroudering de ontwikkeling van nieuwe motorische vaardigheden beïnvloedt. Dit is gedaan door middel van een Discrete Sequence Production (DSP) taak. Deze versie van de taak bestond uit een sequentie van drie toetsen en uit een sequentie van zes toetsen. Het onderzoek is uitgevoerd over twee achtereenvolgende dagen. Beide dagen bestonden uit een oefenfase van negen blokken. Op de tweede dag werd er na de oefenblokken een testblok uitgevoerd bestaande uit een sub-blok bekende en een sub-blok onbekende sequenties. Verder hebben de participanten een getal-symbool substitutietaak en een visuospatieële werkgeheugen taak uitgevoerd om respectievelijk verwerkingssnelheid en werkgeheugen te bestuderen. De participanten van dit onderzoek konden worden verdeeld in een groep jongeren (18-23) en een groep ouderen (74-85). De resultaten laten zien dat de ouderen substantieel langzamer waren in vergelijking tot de jongeren voor zowel de bekende als onbekende sequenties. Het gebruik van motor chunks was ook minder voor de ouderen, maar ze hadden nog steeds een positieve chunking index. Dit duidt op het gebruik van chunking modus. Analyse liet ook zien dat met name ouderen profiteren van een langere oefenfase. De groei van de chunking index stagneerde voor de jongeren, terwijl de groei bij de ouderen doorzette over de blokken. Verder zijn er geen effecten gevonden wat betreft de conditie van de verwerkingssnelheid en het werkgeheugen op de ontwikkeling van motorische vaardigheden.

Introduction

This study explores how ageing influences the capacity to develop new motor skills over time. The capacity of developing such skills is critical to functional independence with advancing age. Because of this importance, underlying mechanisms of this development will be discussed as well. These mechanisms seem to change when growing old. One of these changes that may be associated with developmental deficits in acquiring motor skills is a decline in cognitive functioning (Bo, Borza, & Seidler, 2009). It is well-known that the cognitive functions of processing speed and working memory decline with age (Park et al., 2002). The decline of the working memory in terms of executive processes that can be specified by a higher sensitivity to interference, a declined ability to retain and control focus of attention, and by an impaired ability to connect arbitrary stimulus features in the working memory (Craik & Salthouse, 2011). This decline of the working memory together with that of processing speed may be an important cause of cognitive inflexibility (Verwey, 2010) and therefore possibly of the development of motor skills.

Another change that has to be taken into consideration is that of the physical condition declining with age. Elderly often suffer from diminished joint flexibility, reduced force control, and increasing tremor (Verwey, 2010). Due to this, elderly experience difficulties with both complex motor skills and fine movements. This suggests a decline in coordination between movements, and a decline in controlling individual movements. What must be noted is that the age-related decline of physical functioning as well as cognitive functioning varies among elderly. Also, there appears to be a smaller decline of cognitive functioning for elderly who are physically more fit (Verwey, 2010).

The influence of ageing on the capacity to develop new motor skills over time can be investigated using a motor sequence learning task. Motor sequence learning refers to obtaining the skill to produce a sequence of movements as effortlessly, fast, and accurate as possible. To obtain this skill, trial-and-error discovery, repeated practice, and an implicit detection of regularity are involved (Abrahamse, Ruitenberg, de Kleine, & Verwey, 2013). Since almost every goal-directed activity uses sequential structures in some sort, and a variety of motor skills needs to be developed to perform most goal-directed activities, the development of motor skills has become a popular research topic (e.g., Abrahamse et al., 2013; Doyon, Penhune, & Ungerleider, 2003).

The motor sequence learning task used in this study is the Discrete Sequence Production (DSP) task. This task typically consists of two series of fixed sequences containing two to seven key-specific stimuli (Verwey, Abrahamse, & de Kleine, 2010). The participants have four to eight fingers resting on four to eight keys corresponding to the specific stimuli. Only after responding to a stimulus by pressing the corresponding key the next stimulus will follow. Reaction time in such a paradigm is assumed to be a sensitive indicator for underlying cognitive control processes. The practice phase of the DSP task often consists of about 500 trials (Abrahamse et al., 2013). Due to the limited number of key presses per sequence, participants tend to learn quickly that the order of the sequences are fixed (Rhodes, Bullock, Verwey, Averbeck, & Page, 2004; Verwey, 2010). These qualities of the DSP task make it applicable to studies regarding preparatory mechanisms and hierarchically controlled sequential action (Rhodes et al., 2004). Another advantage of using the DSP task is that the physical demands of pressing keys are low (Verwey, 2010).

A cognitive model that accounts for the capacity to develop sequential skills is the Dual Processor Model (DPM). The DPM consists of two processors, namely the cognitive and the motor processor. During early practice, reaction mode is used. In this mode, seen in figure 1A, the cognitive processor translates every key-specific stimulus into the associated response, and cues the motor processor to execute the response. After a certain amount of practice participants may develop an associative response mode. In the associative mode, execution of sequences still partly takes place under stimulus-based control, but the response selection is primed by preceding events as can be seen in figure 1B. The ongoing response selection is facilitated by the developing sequence knowledge. Ultimately, participants get familiar with the sequence and mental representations of parts of these sequences will develop. These mental representations are called motor chunks. The developed motor chunks allow the cognitive processor to select and load chunks from the long-term memory into the motor buffer as a single response. Figure 1C shows how the cognitive processor triggers the motor processor to execute the movement series from the motor buffer in a relatively autonomous way (Abrahamse et al., 2013; Verwey, 2001). According to Miller (1956), only around seven items can be stored in the working memory. Due to the integration of information into motor chunks, more information can be stored in the working memory, thus loaded in the motor buffer. This way, limitations of human information processing can be bypassed (Verwey, Abrahamse, & Jiménez, 2009).

When executing a DSP task in chunking mode, participants make minimal use of the key-specific stimuli except for the first stimulus that initiates the chunk (Verwey & Wright, 2014). The response to this initiating stimulus is relatively slow compared to that of other stimuli because the chunk corresponding to this stimulus has to be prepared. When more chunks are needed to execute a sequence, a slower response can be seen at the stimulus where initiation of a new chunk takes place. This point of slowing down is called the concatenation point because this is the point where two chunks are concatenated (Abrahamse et al., 2013).

Chunking mode seems the most efficient way to execute a motor task, but in some cases associative mode is used despite motor chunks being available. For instance when alterations – such as adding a tone counting task to the original DSP task – are made (Verwey et al., 2010). The cognitive processor and the motor processor compete with each other to initiate responses of a familiar sequence. As shown in figure 1C, the cognitive processor selects each response on basis of presented stimuli, whereas the motor processor selects responses stored in the motor buffer as chunks (Abrahamse et al., 2013; Verwey, 2001).

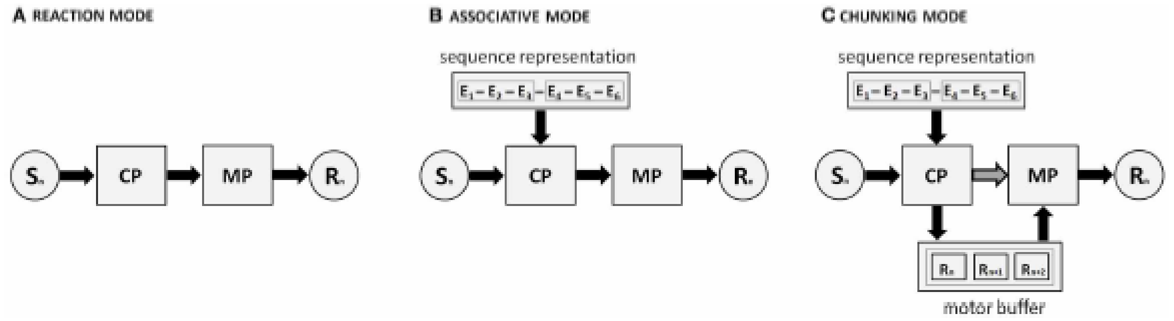

Figure 1 ***the Dual Processor Model (DPM) consisting of a cognitive processor (CP) and a motor processor (MP), and its execution modes – reaction mode (A), associative mode (B), and chunking mode (C). (A)*** *The CP translates every key-specific stimulus (S_n) into the associated response (R_n), and cues the MP to execute R_n..* ***(B)*** *In the associative mode sequence knowledge starts to develop. The execution of sequences still partly takes place under stimulus-based control, but the response selection is primed by preceding events (E).* ***(C)*** *Ultimately, motor chunks develop. These chunks allow the CP to select and load chunks from the long-term memory into the motor buffer to trigger the MP to execute the chunks as one R. It also shows the competition between the associative and the chunking mode (Abrahamse et al., 2013).*

Several studies have suggested that elderly may have difficulty learning motor skills due to a limited ability to develop or to use motor chunks (e.g., Bo et al., 2009; Shea, Park, & Braden, 2006; Verwey, 2010). The study by Bo et al. (2009) showed that the proportion of elderly not showing signs of chunking was higher compared to young adults. When elderly were executing the sequence in chunking mode, the length of the chunks was significantly shorter than that of the young adults. Also, more practice was needed in order to remember a new sequence (Bo et al., 2009). This is in line with the assumption that elderly tend to rely more on external stimuli and that they develop associations between successive responses in a familiar sequence. This associative learning makes it possible to improve without switching to chunking mode (Abrahamse et al., 2013; Verwey, 2010). But what has to be noted is that not only the execution of sequence tasks in the chunking mode declines with age, but also that of reaction and associative mode (Verwey, 2010).

According to Bo et al. (2009), a majority of the tested elderly still developed a consistent chunking pattern during motor sequence learning. However, in this study one of the requirements was to execute the sequence from memory. This may have forced the participants to use chunking mode (Verwey, 2010). Shea, Park, and Braden (2006) who did study the use of motor chunks without imposing a memorization task did not find any indications of elderly using motor chunks. They stated that older adults were not able to develop a consistent motor sequence structure at all (Shea et al., 2006).

It is known that elderly are significantly slower in motor sequence learning tasks compared to young adults (Verwey, 2010). But the reason why elderly have more difficulty in developing motor skills remains unclear. Because of the task differences and contradictory findings of the studies of Bo et al. (2009) and Shea et al. (2006) reaction times of young adults and elderly will be compared in this study, wherein I will look at the chunking of both age groups. The strength of chunking will be observed to see if motor chunks are indeed weaker for elderly than for young adults. The studies mentioned above both have a relatively short practice phase compared to this study. It is possible that a longer practice phase will result in the development of motor chunks for elderly. Therefore, I hypothesize that extended practice results in the development of chunks for young adults and for elderly. Another hypothesis I will study is that the impaired execution of a motor sequence task – thus the impaired ability to develop new motor skills – can be attributed to the declines in processing speed and working memory. Because of these declines, chunking is hypothesized to be weaker for elderly compared to young adults. A digit-symbol substitution task (Wechsler, 1958) and a visuospatial working memory task (Luck & Vogel, 1997) will be used to study respectively processing speed and working memory (Craik & Salthouse, 2011).

Methods

Participants

In total, 36 participants volunteered. 18 of the participants were young adults and the other 18 were elderly. The recruited young adults – 7 male and 11 female – were aged 18 to 23 (M: 20.61; SD: 1.20) and the elderly – 13 male and 5 female – who participated were aged 74 to 85 (M: 79.22; SD: 3.47). The young adults were recruited by using a participant-pool. The inclusion criteria to participate for both the young adults and elderly were that they did not suffer from cognitive or motor impairments, that they were right-handed, and that they mastered the Dutch language.

Tasks

The primary task performed by the participants was the DSP task. In this task six white 38mm x 38mm squares were displayed on a computer screen. These squares were framed by a black line and shown on a white background. Between the third and the fourth square, the letter ‘H’ was presented. This letter was used as an indicator where to place your fingers on the keyboard. The surrounding letters, DFG and JKL, were the letters used for this task. When a square lit up green, participants pressed the associated key with their left or right ring, middle, or index finger. When the response corresponded to the associated key, the square turned white again and another key lit up.

Each participant executed two fixed sequences of stimuli, a three-key sequence and a six-key sequence. After a sequence had been finished, the display went blank for 1000ms to indicate completion of the sequence. Then the framed squares were presented for 500ms to 1000ms and the first stimulus of a sequence was given. When the wrong key was pressed an error message appeared and the ongoing sequence was aborted. The sequences were divided among the participants so that each key was pressed as often on all sequential positions. This way all six fingers contributed as much to the response time at each sequential position.

The experiment was spread over two consecutive days. The DSP task on the first day consisted of a nine block practice phase. Each block consisted of 48 trials and was divided into two sub-blocks by a 40 second break. The three-key and six-key sequences were executed as often in each block, but in random order. Each practice block was followed by a two minute break in which the percentage of errors and the average response time was presented on the screen. The second day also began with nine practice blocks, but ended with a test block. This test block consisted of two sub-blocks of 24 trials each. In one sub-block the familiar sequences were presented and in the other sub-block random three-key and six-key sequences were introduced. The order of the sub-blocks was counterbalanced. In the test block, no error percentage or average response time feedback was given.

Procedure

Before starting the experiment we tried to preclude as many distractions as possible (e.g. turning off the telephone). The first day participants filled out an informed consent form before starting the experiment. When providing the informed consent, the participants were informed that they could be watched on camera during the experiment. After that, the participants filled out the Edinburgh handedness inventory of Oldfield (1971) to confirm they were right handed. A level of fatigue (on a 1 to 10 scale) was given by the participants before starting the DSP task and after every three practice blocks. After the sixth practice block a digit-symbol substitution task (Wechsler, 1958) was administered wherein participants had to fill in as many symbols corresponding to a number from one to nine within 90 seconds. After the nine practice blocks the first day had come to an end and the participants were given an activity questionnaire to determine the level of physical activity.

The second day started with filling out the fatigue score and a visuospatial working memory task (Bo & Seidler, 2009; Luck & Vogel, 1997). In this test a random number (2 – 8) of differently coloured squares was presented for 100ms and then disappeared. After that, the squares reappeared and one of them was encircled. Then, the participant had to answer if the encircled square was of the same or of a deviating colour. After this test the participant continued with the DSP task. Like on the first day, the fatigue score was filled out every three blocks. The ninth practice block of the second day was followed by an explicit knowledge questionnaire wherein participants were asked to write down the letters corresponding to the three-key and six-key sequences they performed. The six keys pressed were printed on top of the paper as a reminder. Furthermore, the participants had to point out the practiced sequences, and they had to choose the right sequences from a set of alternatives. After the explicit knowledge questionnaire, the participants performed the test block that consisted of a sub-block containing familiar sequences and a sub-block of unfamiliar three-key and six-key sequences. After the test block the experiment was ended.

Apparatus

Stimulus presentation, timing and data collection was done by the use of the experimental software package of E-prime. This software was installed on a Dell OptiPlex 9010 Premier desktop on which all unnecessary computer services had been switched off so nothing would interfere with the software. The stimuli were shown on a 22” LG Flatron E2210 computer display. A QWERTY keyboard was used to respond to the stimuli. For the data analysis IBM SPSS Statistics 23 was used.

Results

Practice Phase

The data gathered for the three-key sequence was analysed by a repeated measures mixed 2 (Age: young adults vs. elderly) x 18 (Block) x 3 (Key) ANOVA with Age as the between-subject variable. The dependent variable was the Reaction Time (RT). The trials with errors were filtered out before running the analysis. The elderly appeared to be much slower than the young adult group, 604ms vs. 295ms, F(1, 34)=55.25, p<.001, $p\eta^2$=.62. The within-subject variable Block showed a significant effect, F(17, 578)=47.33, p<.001, $p\eta^2$=.58. This means that when practicing, the RTs of the participants became faster over the blocks. A significant interaction effect was found for Block x Age, F(17, 578)=2.85, p=<.001, $p\eta^2$=.08. This can be seen in figure 2. It shows that both elderly and young adults got faster along the blocks, but that their motor skills develop differently. The within-subject variable Key showed a significant difference in RT, F(2, 68)=82.79, p<.001, $p\eta^2$=.71. For the interaction of Key x Age there was an effect of F(2, 68)=4.13, p=.02, $p\eta^2$=.11. For Block x Key, F(34, 1156)=7.70, p<.001, $p\eta^2$=.19 was found. The RTs on the keys got faster as the number of executed blocks increased. For Block x Key x Age there was a significant interaction effect, F(34, 1156)=1.67, p=.01. $p\eta^2$=.05. This means that the RTs on the age groups developed differently along the keys and over the blocks, and that the RTs over the keys also differed over the blocks for both age groups.

To analyse the data of the six-key sequence a repeated measures was conducted in a mixed 2 (Age: young adults vs. elderly) x 18 (Block) x 6 (Key) ANOVA with Age as the between subject-variable. The dependent variable was the RT. The trials with errors were filtered out before running the analysis. Again, a main effect for the variable Age was found, 598ms vs. 220ms, F(1, 34)=53.53, p<.005, $p\eta^2$=.61. The within-subject variable Block showed a significant effect, F(17, 578)=69.33, p<.001, $p\eta^2$=.67. This means that when practicing, the RTs of the participants became faster over the blocks. A significant interaction effect was found in Block x Age, F (17, 578) =3.07, p=<.001, $p\eta^2$=.08. Thus, the age groups develop motor skills differently along the blocks. This can be seen in figure 3. The within-subject variable Key showed a significant difference in RT, F(5, 170)=39.81, p<.001, $p\eta^2$=.54. For the interaction of Key x Age F(5, 170)=3.64, p=.004, $p\eta^2$=.10 was found. For Block x Key the interaction effect was also significant, F(85, 2890)=6.88, p<.001, $p\eta^2$=.17. This means that the RTs on the keys became faster along the number of blocks executed. For Block x Key x Age there was a significant interaction effect, F(85, 2890)=1.93, p<.001. $p\eta^2$=.05. Thus the RTs on the age groups developed differently along the keys and over the blocks, and that the RTs over the keys also differed over the blocks for both age groups.

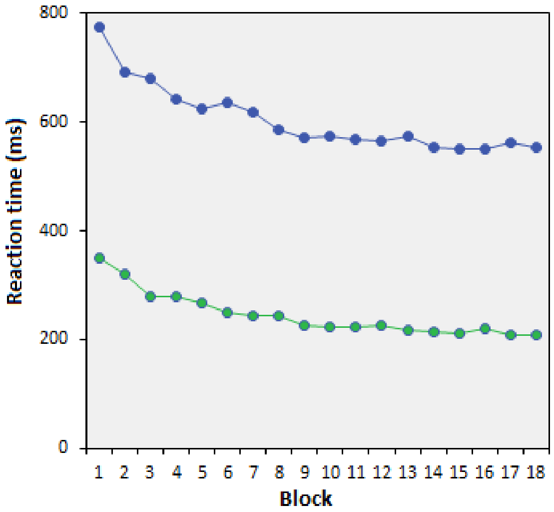

Figure 3 the reaction time (in ms) on the three-key sequence per block for both the elderly and the young adults

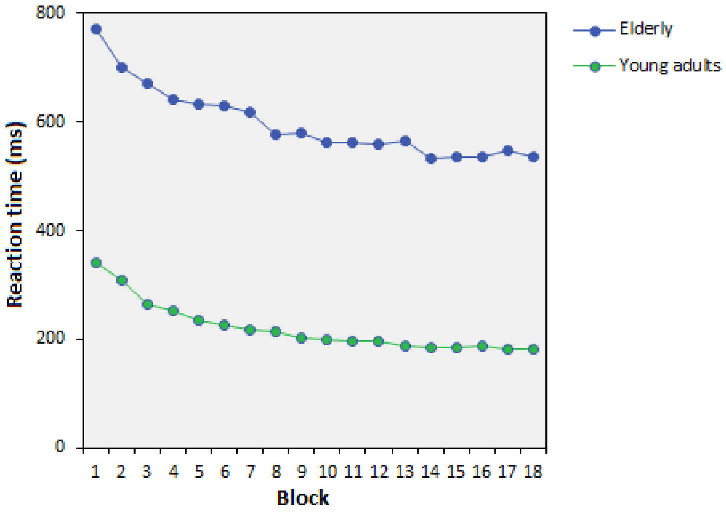

Figure 2 the reaction time (in ms) on the six-key sequence per block for both the elderly and the young adults

To analyse the development of motor skills the chunking index was calculated for every block by subtracting the average of the RTs on the second and third key from the RT on the first key. The trials with errors were filtered out and no distinction was made between the three- and six-key sequences. To test whether an extended practice phase results in the development of chunking mode for young adults as for elderly a repeated measure mixed 2 (Age: elderly vs. young adults) x 18 (Block) ANOVA was conducted with Age as the between-subject variable and the Chunking Index as the dependent variable. The chunking index of the elderly was significantly lower than for the young adults, 143ms vs. 230ms, F(1, 34)=6.13, p=.01, $p\eta^2$=.15. The within-subject variable Block showed a significant effect, F(17, 578)=14.96, p<.001, $p\eta^2$=.31. This indicates that the chunking index of the participants became larger over the blocks. A contrast between the tenth and eighteenth block – thus the second day of the experiment – illustrated this overall increase of the chunking index, $M_{difference\ 18-10}$ = 32ms, p=.50. For Block x Age the interaction effect was significant, F(17, 578)=2.51, p<.001, $p\eta^2$=.07. This is shown in figure 4. It indicates how the chunking indexes of elderly and young adults develop differently over the eighteen blocks. The contrast between the tenth and eighteenth block for both the elderly, $M_{difference\ 18-10}$ = 59ms, p=.01, and the young adults, Mdifference 18-10 = 5ms, p=.48, was used to illustrate this overall increase of the chunking index for the age groups. As can be seen from the contrast and in figure 4, the young adults their development of the chunking index stagnates whereas the chunking index of the elderly keeps getting higher.

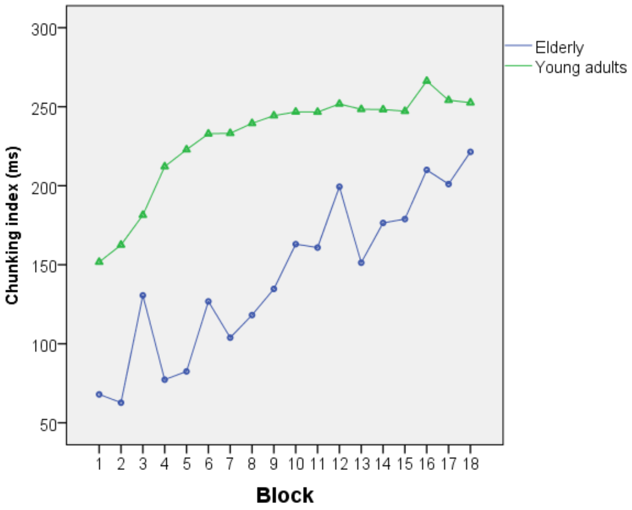

Figure 4 the chunking indexes (in ms) of elderly and young adults improving across the eighteen practice blocks

Test Phase

A repeated measures mixed 2 (Age: elderly vs. young adults) x 2 (Familiarity: unfamiliar vs. familiar) x 3 (Key) ANOVA was used to analyse the data for the three-key sequence. Age was used as between-subject variable and RT was the dependent variable. The trials with errors were filtered out before running the analysis. A general age difference was found on RT between respectively the elderly and the young adults, 675ms vs. 360ms, F(1, 34)=65.15, p<.001, $p\eta^2$=.66. The within-subject variable Familiarity showed a significant difference in RT, F(1, 34)=341.75, p<.001, $p\eta^2$=.91. This confirmed that the RT on the familiar sequence was significantly faster compared to that of the unfamiliar sequence: 380ms vs. 655ms. The Familiarity x Age interaction effect was found to be significant, F(1, 34)=7.07, p=.01, $p\eta^2$=.17. This means that there is a difference between the reaction times on the familiar and unfamiliar sequences for the young adults, 517ms vs. 203ms, and elderly, 792ms vs. 557ms and that the development of the RTs is different for both age groups. The within-subject variable Key also showed a significant difference in reaction time, F(2, 68)=49.27, p<.001, $p\eta^2$=.59. The Familiarity x Key interaction effect was found to be significant, F(2, 68)=82.75, p<.001, $p\eta^2$=.71. This means that the performance on the keys differed significantly per Familiarity and that practice has an influence on the time in which the keys are pressed. No significant interaction effect was found for Key x Age, F(2, 68)=1.05, p=.36, $p\eta^2$=.03. No interaction effect of Familiarity x Key x Age was found either, F (2, 68) =1.41, p=.25, $p\eta^2$=.04. This means that no differences were found between the two age groups when looking at the reaction times for every key per familiarity of the sequence. This interaction effect is illustrated in figure 5.

For the six-key sequence a repeated measures mixed 2 (Age: elderly vs. young adults) x 2 (Familiarity: unfamiliar vs. familiar) x 6 (Key) ANOVA was used with Age as between-subject variable. A general age related difference in RT of 677ms vs. 354ms was found, F (1, 34) =78.65, p<.001, $p\eta^2$=.70. The within-subject variable Familiarity showed significantly faster RTs on the familiar sequence compared to the unfamiliar sequence, 359ms vs. 672ms, F(1,34)=474.18, p<.001, $p\eta^2$=.93. The Familiarity x Age interaction effect was significant, F(1, 34)=6.76, p=.01, $p\eta^2$=.17. This means that there is a significant difference between the RTs on the familiar and unfamiliar sequences for the young adults, 529ms vs. 179ms, and elderly, 814ms vs. 539ms. The within-subject variable Key also showed a significant difference in RT, F(5, 170)=22.90, p<.001, $p\eta^2$=.40. A more important significant effect was found for Familiarity x Key, F(5, 170)=37.99, p<.001, $p\eta^2$=.53, meaning that the performance on the keys differed significantly across the familiar and unfamiliar sequence, with the familiar sequence executed significantly faster. Unlike with the 3-key sequence, a significant effect was found when looking at the reaction times on the keys for both age groups, F(5, 170)=2.40, p=.039, $p\eta^2$=.07. No significant interaction effect was found for Familiarity x Key x Age, F(5, 170)=1.38, p=.23, $p\eta^2$=.04. The interaction effect is illustrated in figure 6

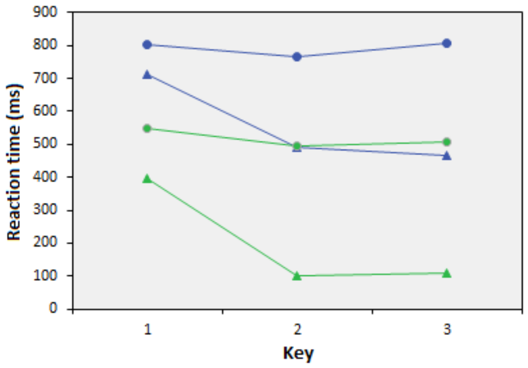

Figure 5 the reaction time per key (in ms) of the elderly and the young adults for both the familiar and unfamiliar three-key sequence.

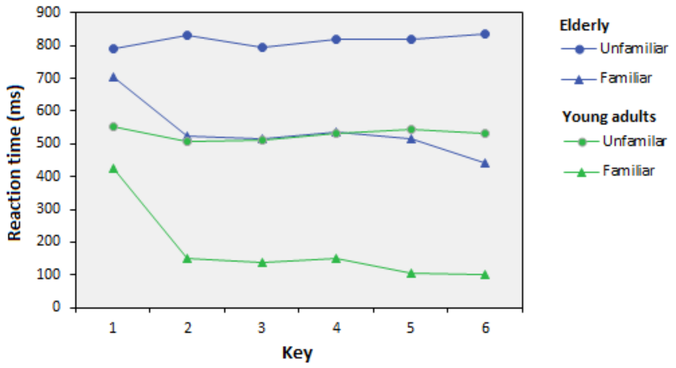

Figure 6 the reaction time per key (in ms) of the elderly and young adults for both the familiar and unfamiliar six-key sequence

Chunking indexes for both the unfamiliar and familiar block were calculated the same way as the chunking indexes of the practice phase. An independent samples T-test was conducted for both the Chunking Index for the Unfamiliar Sequence (CIUS) and the Chunking Index for the Familiar Sequences (CIFS) as test variables, and with Age as grouping variable to establish the starting condition of the chunking indexes of the age groups (CIUS), and whether motor chunks are indeed weaker for elderly compared to that of young adults (CIFS). For the CIUS was found to be significantly lower for the elderly compared to the young adults, -3ms vs. 45ms, t(34)=-1.68, p=.05. Also the CIFS was found to be significantly lower for the elderly, 209ms vs. 285ms, t(34)=-1.78, p=.04.

Furthermore, a repeated measures mixed 2 (Age: elderly vs. young adults) x 2 (Familiarity: unfamiliar vs. familiar) ANOVA was conducted with Age as the between-subject variable and the Chunking Index as the dependent variable to look at what effect practice has on the execution of sequences. The chunking index of the elderly was found to be lower compared to the index of the young adults when no distinction was made between the familiarity of the sequences, 103ms vs. 165ms, F(1, 34)=3.51, p=.04, $p\eta^2$=.09. The within-subject variable Familiarity did show a significant effect, F (1, 34) =220.89, p<.001, $p\eta^2$=.87. From this effect there be derived that the chunking index of the participants was significantly higher for the familiar sequences compared to the unfamiliar sequences, 247ms vs. 21ms. For Familiarity x Age no significant interaction was found, F (1, 34) =.86, p=.36, $p\eta^2$=.03. This means that there was no significant difference in the chunking index of the unfamiliar and familiar sequences between the age groups, -3ms vs. 209ms for the elderly, and 45ms vs. 285ms for the young adults.

Digit-Symbol Substitution Task

The data regarding the processing speed, gathered by collected using the digit-symbol substitution task, was analysed using Pearson correlations. The variables used were the Chunking Index of Familiar Sequences (CIFS), the Number of Items in 90 seconds, and the Number of Items Recalled. This was done for both age groups. The correlation between CIFS and the Number of items in 90 seconds for elderly was significant, r=-.48, p=.02. This means that the number of items written down in 90 seconds is a weak predictor for the development of motor skills for the elderly (r^2=.23). For the young adult group no significant correlation was found between CIFS and the Number of Items in 90 seconds, r=.17, p=.26. The correlation between CIFS and the Number of Items Recalled for elderly was not significant, r=-.12, p=.32. Also for the young adults the correlation between CIFS and the Number of Items Recalled was not significant, r=.04, p=.44.

Visuospatial Working Memory Task

To analyse if an impaired development of motor skills can be attributed to a decline of visuospatial working memory, the data regarding the visuospatial working memory task was analysed using Pearson correlations. The variables used were the CIFS, and the Median Capacity. This was done for both age groups. The correlation between CIFS and the Median Capacity for elderly was not significant, r=.06, p=.41. Also for the young adult group no significant correlation was found between CIFS and the Median Capacity, r=.12, p=.32.

Discussion

The goal of this study was to explore how ageing influences the capacity to develop new motor skills over time. Overall, elderly were substantially slower when executing the DSP task. This was true for when the sequences were unfamiliar as well as when they were familiar. Further analysis was done according to three hypotheses. The first hypothesis stated that motor chunks are weaker for elderly compared to that of young adults. This was confirmed by looking at the chunking index of both age groups for the familiar sequence in the test phase. Despite of the chunking index (CIFS) of the elderly being lower compared to that of the young adults, the elderly still had a positive chunking index. This can be attributed to the relatively slow reaction on the first stimulus compared to the others that is typical for motor chunking. These differences be seen in figure 5 and 6. It suggests, in terms of the DPM, that the elderly did switch from associative mode to chunking mode. That resulted in the execution of the sequences in a relatively fast and autonomous way. Also, an increase of the chunking index over the practice blocks was found in this study (see figure 4). This is in line with the study of Bo et al. (2009) where the majority of the elderly developed a consistent chunking pattern. Therefore, forcing the participants to execute the sequences from memory did not necessarily force elderly into using chunking mode as suggested by Verwey (2010). The findings of Shea et al. (2006) that elderly are not capable of developing a consistent motor sequence structure can therefore not be confirmed by this study.

Secondly, it was hypothesized that the extended practice phase causes motor chunks to develop for both young adults and elderly. This was confirmed by this study. However, the familiarized chunking index of the young adults was substantially higher compared to that of the elderly. Throughout time, the increase of chunking index of the young adults stagnated, whereas the elderly their chunking index was still developing. This can be seen in figure 4. It is therefore very likely that elderly simply require more practice than young adults to develop and use motor chunking. Despite of this effect of practice found in the practice phase, caution is required confirming the hypothesis. In the test phase, the difference of the chunking indexes between the familiar and unfamiliar sequences was bigger for the young adults than for the elderly. This means that the young adults improved more when a sequence was practiced, even though the practice phase was extended. Thus, the elderly profit from an extended time to practice motor skills and seem to develop chunking, but the development of those skills are still less compared to that of the young adults. This may be caused by cognitive decline. Verwey (2010) suggested that declines in processing speed and working memory may be the cause of cognitive inflexibility. A possible explanation for this need for practice could be the declined ability to connect arbitrary stimulus features in the working memory associated with ageing (Craik & Salthouse, 2011). This assumption led to the hypothesis that the impaired ability to develop new motor skills can be attributed to declines in processing speed and working memory. The assumption that cognitive functioning declines with age is supported by several studies (e.g., Bo et al., 2009; Park et al., 2002). Besides that, it is also well covered through research that the visuospatial working memory is closely related to the use of the motor buffer to make motor chunking possible (e.g., Verwey, Abrahamse, & Jiménez, 2009). Because of this and because of the findings regarding extended practice phase a significant correlation was expected. However, processing speed appeared to be a weak predictor and for working memory the hypothesis could not be confirmed. Therefore, the declines in processing speed and working memory cannot be interpreted as a cause of the impaired development of new motor skills.

The extended practice phase may have minimalized the effect of cognitive impairments on the execution of motor sequence learning tasks (in chunking mode) as suggested by Verwey (2010). Though, from this study it seems unlikely that practice minimalized the effects for processing speed and working memory. No correlation was found on the visuospatial working memory task, and the correlation of the score on the digit-symbol substitution task was negative. This negative outcome would mean that the higher elderly score on this task, the lower the chunking index will be on the familiar task. Thus, the better the elderly score on processing speed, the slower they would execute the motor sequences. Because this is contradictory to the expectations formed by for example Park et al. (2002) and Verwey (2010) it is recommended to study the effect of processing speed and working memory on the development of motor skills in more detail before drawing any conclusions.

In general, for both the practice and the test phase it should be noted that the chunking indexes are the result of taking both the three- and the six-key sequence together. Despite that the differences may be small when running analysis with the chunking indexes of both sequences, there is a chance that it could be the difference of a result being significant or not. It may be that the elderly cope differently with the two sequences. They may for instance use smaller chunks (Bo et al., 2009). That would mean that the chunking index for the six-key sequence, thus also for taking the average of three- and six-key sequence, is no good representation of the motor skill development of elderly since more chunks would be used. For future research I suggest that there will be focused on what cognitive impairments have the biggest impact on the motor skill development of elderly, and if and into what extend they can be bypassed by practice.

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