COGNITIVE CONTROL IN MOTOR SEQUENCE LEARNING

AN ANALYSIS OF POST-ERROR SLOWING AND SEQUENCE SWITCHING OVER THE LIFESPAN

BACHELOR THESIS

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Content

SAMENVATTING

In dit onderzoek werd de rol van cognitieve controle bij motorische reeksen onderzocht bij participanten met verschillende leeftijden. De verschillen bij de fenomenen "post-error slowing (PES)" en "sequence switching (SS)" in het leren van motorische reeksen werden geanalyseerd voor vier leeftijdsgroepen. De beide fenomenen waren al aangetoond bij taken met een simpele reactietijd, maar in dit onderzoek werd gekeken of dit ook voor complexe taken kon worden vastgesteld.

Een bestaande dataset, verzameld in drie eerder uitgevoerde onderzoeken, werd geanalyseerd. De participanten uit de vier leeftijdsgroepen waren kinderen, jongvolwassenen, ouderen en personen van middelbare leeftijd, in totaal 96 deelnemers. Zij voerden allen een "discrete sequence production task" (DSP taak) uit, waarbij er een onderscheid gemaakt werd tussen korte (3-toetsen) en lange (6-toetsen) reeksen.

Resultaten bevestigden deels de hypothese dat PES verloopt in een U-vorm, maar dit verschijnsel werd alleen significant aangetoond bij de korte reeksen, niet bij de lange reeksen. De jongvolwassenen laten de minste tekenen van PES zien. Ook bij SS verloopt de ontwikkeling van PES in een U-vorm, en weer alleen bij de korte reeksen, niet bij de lange reeksen.

Concluderend kan gesteld worden dat bij zowel PES als SS, de U-vormige ontwikkelingscurve werd gevonden bij de leeftijdsontwikkeling door de jaren heen, maar alleen bij de korte reeksen. Toekomstig onderzoek zou zich moeten richten op langere reeksen, om te onderzoeken hoe de ontwikkeling bij de verschillende leeftijden daar plaatsvindt.

SUMMARY

This study investigated the role of cognitive control in motor sequence learning over the lifespan. The differences in the phenomena "post-error slowing (PES)" and "sequence switching (SS)" in motor sequence learning were analyzed for four age groups. Both phenomena had already been demonstrated for simple reaction times tasks, but in this study it was investigated if they did also emerge in more complex tasks.

An existing data-set, collected in three previously performed studies, was analyzed. The data was gathered from participants from four age groups; children, young adults, middle-aged and elderly people; 96 participants in total. They all performed a discrete sequence production task (DSP task), whereby a distinction could be made between short (3-key) and long (6-key) sequences.

Results confirmed the hypothesis that PES developed in an U-shaped form, but this is only the case for the short sequences, not for the long sequences. The young adults show the least signs of PES. Likewise, for the SS data the development occurred in an U-shaped form, but only for the short sequences, not for the long sequences.

In conclusion, it is stated that both PES and SS showed an U-shaped form in their development over the lifespan, but only at the short sequences. Future research should focus on sequences longer than three key presses, to discover their exact development over the lifespan.

INTRODUCTION

A general development is that the world population is aging (King, Fogel, Albouy & Doyon, 2013), and a well-known saying is that old age is defective. Therefore it is important to investigate what the consequences of aging for humanity are. In this study the focus is on a specific development important for daily functioning; “motor sequence learning”. “Motor sequence learning” is the increasing fusion of a separate collection of activities into a smooth motion sequence (King et al., 2013; Seidler, Bo & Anguera, 2012). Good examples are when a child is learning how to ride a bike, or when a young adult is learning how to drive a car. In the beginning it takes much effort to go through the separate steps of movement. However, in the course of time and with exercise, the action becomes more and more automatic. To process this learning, it is important to have cognitive control. Cognitive control refers to the ability of the human brain to perform tasks and to repress certain replies, and produce other ones instead (Botvinick, Braver, Barch, Carter & Cohen, 2001; Kadosh, Gevers & Notebaert, 2011). The aim of the present study is to investigate whether there are differences in this cognitive control during motor sequence learning between children, young adults, middle-aged and elderly persons.

SEQUENTIAL MOTOR SKILL

A task that is well suited for examining the learning and performance of sequential motor actions is the discrete sequence production (DSP) task (see Abrahamse, Ruitenberg, de Kleine & Verwey, 2013). In brief, a participant performing the DSP task reacts to a highlighted square on a computer screen, by pressing the matching key on the keyboard as fast as possible. This has implications when sequences of key presses are repeated in a short period of time. The result is that a translation occurs, whereby single key presses are combined into a single representation, which is called a “motor chunk”. Motor chunks, according to Verwey (2010, p. 207), are “integrated representations in memory, which allow selection and execution of the required series of key presses as a whole, while the responses themselves are associated”. Research has been done with the DSP task to examine how this “chunking” takes place.

Underlying learning mechanisms which could possibly be responsible for motor chunking are described in the dual processor model (DPM) (Abrahamse et al., 2013; Ruitenberg, Abrahamse & Verwey, 2013; Verwey, 2001, 2010; Verwey, Abrahamse, Ruitenberg, Jiménez, de Kleine, 2011). In this model a distinction is made between two processors: the cognitive processor and the motor processor. These two processors collaborate during a task. The difference between them is the role they are playing when a DSP task is performed (Abrahamse et al., 2013). There are two possible modes. A task is performed in the reaction mode when the cognitive processor combines the distinct key presses of one stimulus with one response, and then the motor processor executes this single action. A task is performed in the chunking mode when single actions are combined as one motor chunk. Then the cognitive processor selects the meanwhile automated motor chunk sequences and the motor processor performs all the actions in this chunk at once. Verwey (2010) and Verwey et al. (2011) discovered a third learning mechanism, associative learning. This learning can be demonstrated in the improvement of output by each sequential step (MacKay, 1982; as cited in Verwey, 2010). To summarize, three learning modes are listed which could be responsible for motor chunking; the reaction mode, the chunking mode and associative learning.

MOTOR SEQUENCE LEARNING THROUGHOUT THE LIFESPAN

Research indeed has shown that the three different learning mechanisms underlie motor sequence learning throughout the lifespan – in other words, people from different ages learn differently. For example, Ruitenberg et al. (2013) showed that, when preadolescent children are compared with young adults, the latter automatize the underlying process of movement sequences to a greater extent. Specifically, it seems that for the children, the sequence execution remains stronger under control of the cognitive processor. In another study, Verwey et al. (2011) compared sequence learning in young adults with sequence learning in middle-aged participants. They observed that the latter showed less improvement in sequence learning, and state the inferior use of motor chunks in middle-aged as the possible cause. Verwey (2010) compared young adults with elderly participants in their learning of motor sequences. It is stated that not only did elderly participants react more slowly in comparison to the young adults but they also, as a group, did not turn into sequence learning where as young adults did. It was also claimed that the elderly participants had difficulties with the use of motor chunks. In the studies of Verwey (2010) and Verwey et al. (2011) it also seemed that middle-aged and elderly people proceeded in the reaction mode, instead of the chunking mode. They also showed signs of associative learning. Also, Boyd, Vidoni & Siengsukon (2007) set the discovery of an deterioration in motor learning in elderly persons, in comparison with young and middle-aged adults. And, not only do young adults respond faster than children, older adults or elderly people; they are the only age group that show convincing signs of sequence learning (Weiermann & Meier, 2012; Verwey, 2010). To summarize, it seems that especially young adults perform discrete movement sequences in the chunking mode, while children, middle-aged and elderly relate on the reaction mode of associative learning.

COGNITIVE CONTROL IN SEQUENCING SKILL

Although previous studies thus observed different sequence learning mechanisms across various age groups, it is unclear whether differences in cognitive control of such sequences underlie these differences in learning. In the present study, we focus on two phenomena of cognitive control that can be related to sequence learning.

The first is post-error slowing (PES). This is the phenomenon in which people delay their reaction time on a task, after making a mistake (Steinborn, Flehmig, Bratzke & Schröter, 2012; Dutilh, van Ravenzwaaij, Nieuwenhuis, van der Maas, Forstmann & Wagenmakers, 2012a; Dutilh, Vandekerckhove, Forstmann, Keuleers, Brysbaert & Wagenmakers, 2012b). PES is normally measured by subtracting the mean reaction times of post-correct trials by the mean reaction times of post-error trials (Dutilh et al., 2012a). Further, Dutilh et al. (2012b) state that the cause of PES is that people become more cautious after they make a mistake, which is related to cognitive control. Hereby older participants slow down stronger after making an error, because they are more cautious (Dutihl, Forstmann, Vandekerckhove & Wagenmakers, 2013). At the same time, people try to avoid the same response they have given, which impedes response repetition and stimulates response alternation (Laming, 1986, 1979; Rabbitt & Rogers, 1977, as cited in Dutilh et al., 2012b).

The second phenomenon is response switching. Hereby a distinction can be made between response repetition and response alternation. Response repetition is the effect that the repetition of a response shortens the response time (Kleinsorge, 1999), and the response alternation effect is the reversed repetition effect (Rogers & Monsell, 1995; as cited in Kleinsorge, 1999). It is stated that performance on a repeated response trial could lead to performance benefits, but when performance on a response alternation trial is worse than on the repeated trial, a switch cost occurs (Koch, Schuch, Vu & Proctor, 2011; Andreadis & Quinlan, 2010)

Since this study investigates the differences between whole sequences, the second cognitive mechanism is called sequence switching (SS). SS is measured by subtracting the mean reaction times of the response alternation trials by the mean reaction times of the response repetition trials of the different sequences.

PES and SS at different ages

As said, people at different ages differ in their learning. It seems that for PES and SS this statement is also true.

To start with, Gupta, Kar & Srinivasan (2009) investigated children between 6 and 11 years old, and saw the process of PES as a development process. Especially PES at simple reaction times, seems to develop in a U-shaped form, where it initially decreases, and then increases with age (Kramer, Humphrey, Larish, Logan & Strayer, 1994; Bedard, Nichols, Barbosa, Schachar, Logan and Tannock, 2002; as cited in Gupta et al. 2009). Also, Dutihl et al. (2013) found more post-error slowing by the elderly, when comparing young (student age) and older (60-80 years of age) participants.

For SS in general, older adults experience an increase in switch costs in comparison with young adults, when performing a switching paradigm with Stroop stimuli (Kray, Eppinger & Mecklinger, 2005). When comparing children and young adults Crone, Bunge, van der Molen & Ridderinkhof (2006) state that at response repetition, the former showed larger response time costs. On the whole, the development of sequence switching is also expected to be shown in an U-shape form, whereby young children and elderly participants are expected to have the largest response time costs (Cepeda, Kramer, Gonzalez de Sather, 2001).

PRESENT WORK

The purpose of this study is to examine PES and SS over the lifespan, to investigate whether these cognitive control mechanisms, that are present during the learning and performance of discrete movement sequences, differ between children, young adults, middle-aged and elderly persons. Both PES and response switching, have been demonstrated for tasks in which simple reaction times are measured. However, it is unknown if they also emerge for more complex actions. The present study tries to answer this question. The DSP task, as described above, was used to asses motor sequence learning.

Two hypotheses were stated, one for PES and one for SS. With respect to PES, it was expected to discover the U-shaped relationship that was also observed in previous studies on simple response times (Kramer et al., 1994; Bedard et al., 2002; as cited in Gupta et al. 2009). Specifically, we expected the middle-aged and elderly participants to show the longest delay after making an error, followed by the children. The young adults are expected to have the least PES.

With respect to SS, again it is expected to find an U-shaped relationship between the four age groups (Cepeda et al., 2001). Hereby the young adults are expected to show the least response time costs, followed by the children, middle-aged and elderly participants (Kray et al., 2005; Crone et al., 2006).

METHOD

PARTICIPANTS

An existing data-set was analyzed, which was collected in previous experiments (Ruitenberg et al., 2013; Verwey, 2010; Verwey et al., 2011). The complete sample consisted of 96 participants: 24 children (aged 10-13 years, mean age=11.3), 24 young adults (aged 18-28 years, mean age=22), 24 middle-aged (aged 55-62 years, mean age=58) and 24 elderly (aged 75-88 years, mean age=79). The middle-aged and elderly participants were screened on health. None of them had troubles with the task on the basis of their health, despite the fact that five middle-aged participant used medication. The experiments were approved by the ethics committee of the Faculty of Behavioral Sciences of the University of Twente.

TASK

The task that participants performed has been described in Ruitenberg et al. (2013), Verwey (2010), and Verwey et al. (2011). However, for the sake of clarity the task will also be described here. Participants had to run through a computer program that consisted of seven blocks. Six were practice blocks, and the last one was a test block. Each practice block consisted of 12 fixed 6-key sequences (R_1-R_6) and 12 fixed 3-key (R_1-R_3) sequences, 24 sequences in total. These were presented in a random order. Also, the responses of the keys followed the fixed order of the stimuli (respectively S_1-S_6 and S_1-S_3), whereby T stands for the response interval between a stimulus and a response of the participant.

To run the blocks participants needed to place their left and right ring, middle and index fingers on the keyboard of the laptop. The keys d, f, g, j, k, and l corresponded with six black horizontally aligned square stimulus placeholders, with a gap between the third and fourth placeholder. On the white background the letter ‘H’ in the middle mimicked the keyboard lay-out. Participants had to press in the corresponding key if a placeholder was filled with green.

Directly after a correct answer, the color changed back to white, and the next stimulus in the sequence was shown. After an incorrect response, an error message was shown for 500 ms. Then the sequence stopped, followed by a 1,000 ms. empty screen after which a new sequence started. After completing a sequence the display turned white for 2,000 ms. to indicate completion of the sequence. The black outlines appeared and stayed hollow for 1,000 ms. after the first block turned green.

In each practice block there was a pause of 40 sec. halfway, and after each practice block there was a pause of at least 4 min. Half of participants experienced a pause halfway in their 6-key sequence of at least 300 ms., to protect them for increasing their expectations of a full sequence. This happened only in the practice blocks, not in the test block. After each block a screen appeared which displayed the percentage of errors and mean RT.

The test block consisted of three sorts of blocks, separated by a 40 sec. pause. First block, the *familiar condition*, showed the same key sequences as in the practice phase. Second block, the *single-stimulus condition*, presented only the first stimulus of the practiced key sequence. The rest of the sequence had to be finished without external guidance. And the third block, the *unfamiliar condition*, showed a new 3-key and 6-key sequence. The order of the three conditions were random divided over the participants. The test block did not contain pauses, and the 3-key and 6-key sequences were randomly divided, 12 sequences per block.

To prevent advantage due to repetition per finger, the keys were counterbalanced across sequential positions. For instance, one participant had the sequence FKL and KFGDJL, the next participant had GLD and LGJFKD, and so on.

Procedure

The procedure for the different age groups are described in Ruitenberg et al. (2013), Verwey (2010), and Verwey et al. (2011), but will also be explained here for clarity. Children were tested at their school, young adults were tested in our lab and the middle-aged and elderly were visited at home. At the start each participant filled in an informed consent form, except the children. In their case, the parents or guardians of each child gave their passive informed consent, after reading an information letter. Afterwards the participants filled in other forms concerning their health and the use of their hands. If participants had any questions during the inquiry, the experimenter answered them. In the end a written instruction on the task was received by the participants, and explained by the experimenter.

The six practice blocks were followed by a questionnaire (the 'recall' test) were participants had to give the order of the letters. The aim of this test was to find out if participants remembered the 3-key and 6-key sequences. On the form of the test, the keyboard was printed, so participants could recall the key presses more easily, and the original keyboard remained in sight. The second test was a 'recognition' test, whereby participants had to select their 3-key and 6-key sequences, both from a list of 12 alternatives. After this test, the test block was performed. In total the experiment took 1.5-2 hours per participant.

Apparatus

The participants performed the task on a computer or a notebook computer. The children used a Pentium IV computer, and the young adults, middle-aged and elderly participants used a Pentium IV notebook computer. In both cases, E-Prime © 2.0 software was used for the stimulus presentation, timing and data registration. The children performed the task on a standard keyboard, but the other participants performed the task on a notebook keyboard. Hereby all the unnecessary programs were switched off of both devices to allow accurate time measurement.

DATA ANALYSIS

Only the training phase was analyzed. Sequences in which one or more errors were made were omitted from the data, as well as sequences with a total execution time of more than 2.5 standard deviations from the mean across participants in an age group. The received data was already prepared partly before the analysis was made. The mean response times per key already have been measured, whereby response time was defined as the time between the presentation of the stimulus, and pressing of the appropriate key. By then, the analysis was made in the following order.

First, two analyses of variances (ANOVAs) were applied to the PES data, one for the 3-key, and one for the 6-key sequences. The analyses contained trial (2: post-correct vs. post-error), block (6: 1 to 6), and key position within the key (2: 3-key or 6-key) as within-subject variables and age group (4: children, young adults, middle-aged and elderly people) as between-subject variable.

Second, two ANOVAs were applied to the SS data, whereby trial (2: repetition vs. alternation), block (6: 1 to 6), and key position within the key (2: 3-key or 6-key) served as within-subject variables and age group (4: children, young adults, middle-aged and elderly people) as between-subject variable.

Third, additional ANOVAs were applied to the PES data, because only a small portion of the data of the participants counted along in the calculations. Therefore, the sixth block was analyzed for the 3-key and the 6-key sequences.

RESULTS

PES for the 3-key sequences

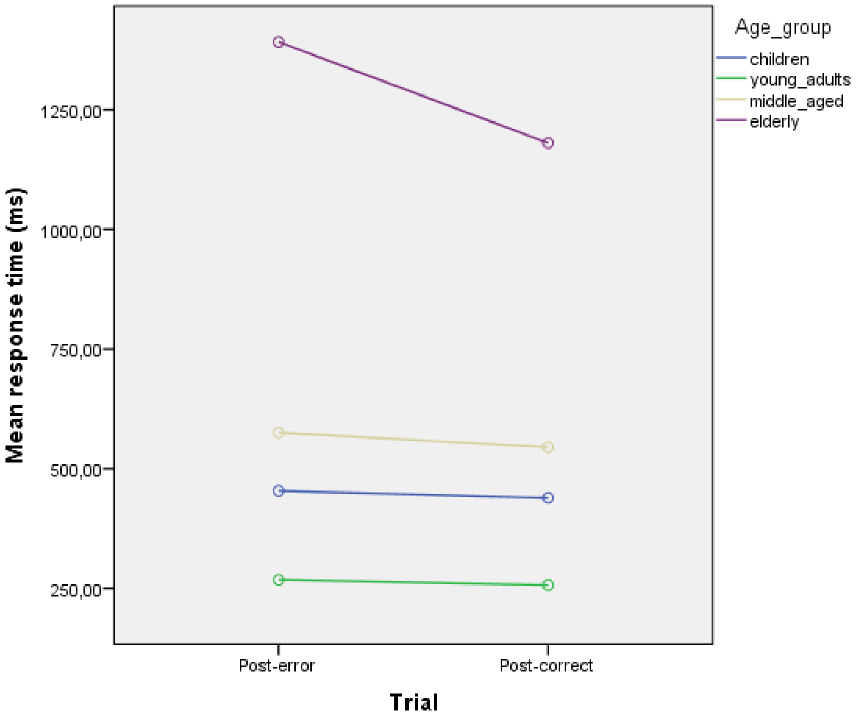
An ANOVA was performed to see whether PES differed significantly for the four age groups in the 3-key sequences. It was applied to trial (2: post-correct vs. post-error), block (6: 1 to 6), and key position within the key (2: 3-key or 6-key) as within-subject variables and age group (4: children, young adults, middle-aged and elderly people) as between-subject variable. Not all of the 96 participants were included in the analysis (table 1), because some made no errors during the task. Therefore, their data was not included in the calculations.

Table 1: *Participants in the PES 3-key sequences*

Age group	N
Children	18
Young adults	8
Middle aged	4
Elderly	14

First, results showed that there was a main effect of age, $F(3,40)=27.67$, $p<.001$), whereby the elderly participants had a significant longer mean response time (1286 ms.) than the middle-aged (560 ms.), children (446 ms.) or young adults (262 ms.). Second, the participants showed a longer response time at the post-error trials (672 ms.) in comparison with the post-correct trials (605 ms.), confirming PES, $F(1,40)= 4.51$, $p<.05$). Third, an interaction effect was found between trial and age group, whereby all age groups demonstrated a longer response time at the post-error trials in comparison with the post-correct trials, $F(3,40)=3.87$, $p<.02$). The elderly participants displayed the largest delay (211 ms.), followed by the middle-aged (30 ms.), the children (15 ms.) and young adults (11 ms.), (see figure 1).

Figure 1: *Mean response times for the post-error and post-correct 3-key sequences as a function of age group*



Last, response times also decreased across blocks (block 1: 768 ms. to block 6: 603 ms.), $F(5,200)=5.60$, $p < .001$) and key presses (key 1: 698 ms. to key 3: 571 ms.), $F(2,80)=4$, $p < .03$).

PES for the 3-key sequences of the sixth block

For not all participants were included in the analysis, an additional ANOVA was applied to show the results of one block. This was the sixth block, because here the participants had the most experience in the task. The ANOVA was applied to trial (2: post-correct vs. post-error), and key position within the key (2: 3-key or 6-key) as within-subject variables and age group (4: children, young adults, middle-aged and elderly people) as between-subject variable. As can be seen from table 2, much more participants were included in the analysis then for all six blocks, although 26 of the 96 participants still remained error free.

Table 2: *Participants in the PES 3-key sequences of the sixth block*

Age group	N
Children	21
Young adults	17
Middle aged	12
Elderly	20

First, results showed a main effect of age, $F(3,66)=26.61$, $p<.001$), whereby the elderly participants had a significant longer mean response time (1195 ms.) than the middle-aged (496 ms.), children (357 ms.) or young adults (242 ms.). Second, no interaction effect was found between trial and age group. Third, response times also decreased across key presses (key 1: 668 ms. to key 3: 458 ms.), $F(2,132)=8.82$, $p < .001$). Last, an interaction effect was found between key and age group, $F(6,132)=2.45$, $p<.05$).

PES for the 6-key sequences

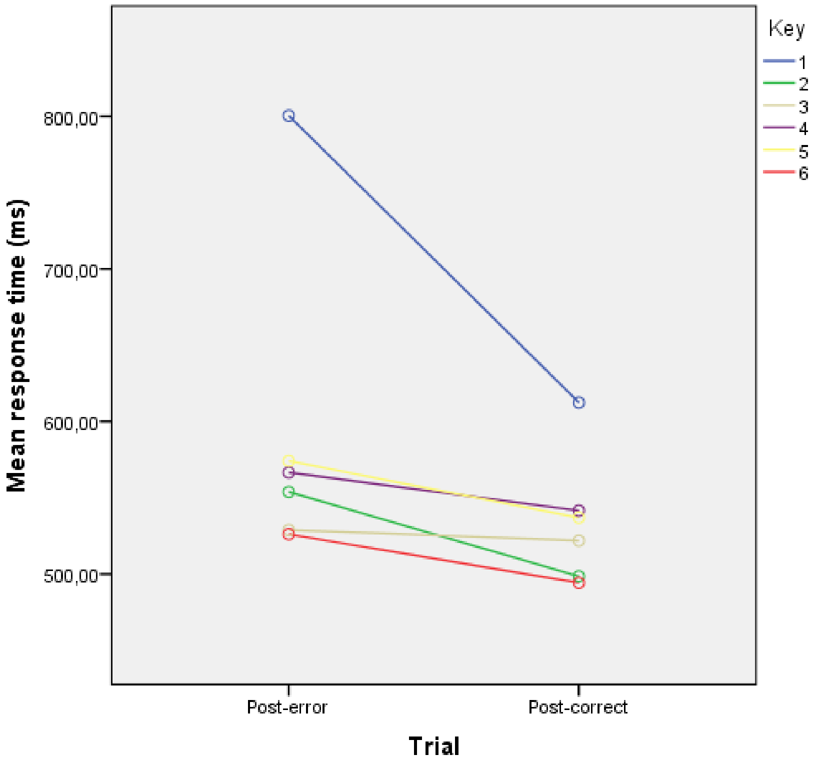
Then, an ANOVA was performed to see whether PES differed significantly for the four age groups in the 6-key sequences. Again, not all of the 96 participants were included in the analysis (table 3), because they did not all made errors.

Table 3: *Participants in the PES 6-key sequences*

Age group	N
Children	10
Young adults	5
Middle aged	3
Elderly	11

First, results showed that there was a main effect of age, $F(3,25)=13.51$, $p<.001$), whereby the elderly participants had a significant longer mean response time (1027 ms.) than the middle-aged (516 ms.), children (432 ms.) or young adults (277 ms.). Second, the participants showed a longer response time at the post-error trials (592 ms.) in comparison with the post-correct trials (534 ms.), confirming PES, $F(1,25) = 8.79$, $p < .01$). Third, no interaction effect was found between trial and age group. Fourth, response times also decreased across blocks (block 1: 796 ms. to block 6: 469 ms.), $F(5,125) = 17.24$, $p < .001$) and key presses (key 1: 706 ms. to key 6: 510 ms.), $F(5,125) = 4.68$, $p < .01$). Last, an interaction effect was found between trial and key, $F(5,125) = 2.57$, $p < .05$), whereby the PES was especially large at key 1 (188 ms.), in comparison with key 2 (32 ms.), key 3 (7 ms.), key 4 (30 ms.), key 5(33 ms.) and key 6 (32 ms.), (see figure 2).

Figure 2: *Mean response times for the post-error and post-correct 6-key sequences as a function of key press*



PES for the 6-key sequences of the sixth block

Again, an additional ANOVA was applied to the sixth block of the 6-key sequences, to see what the effects of PES are for one block. Of the 96 participants in total, 32 participants made no errors, and therefore were not included in the data (see table 4).

Table 4: *Participants in the PES 6-key sequences of the sixth block*

Age group	N
Children	19
Young adults	16
Middle aged	12
Elderly	17

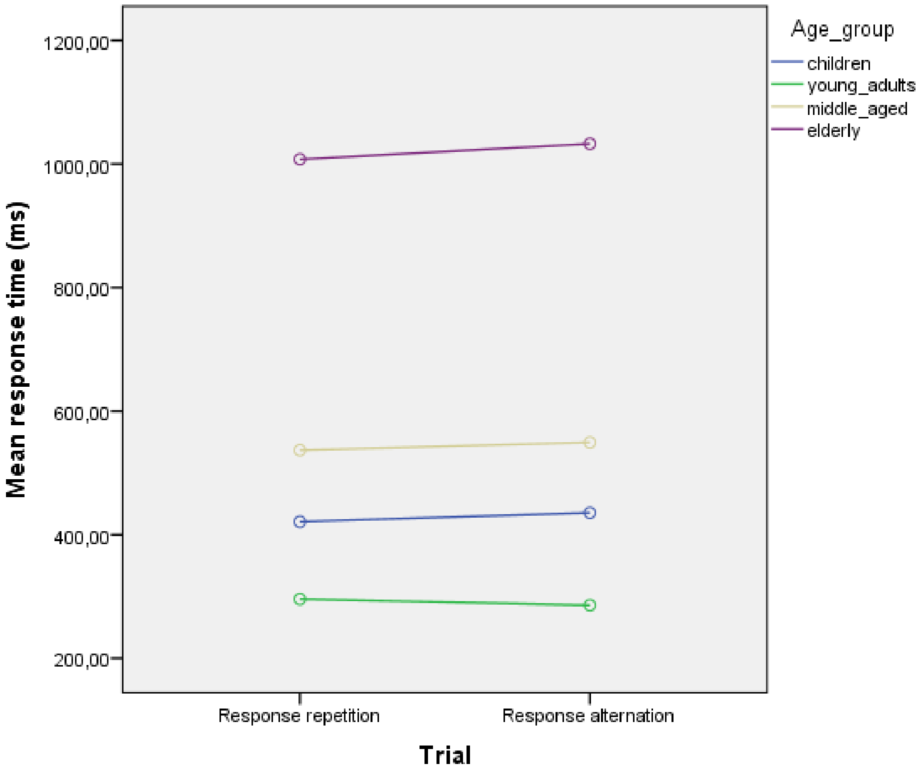
First, results showed a main effect of age, $F(3,60)=31.67$, $p<.001$), whereby the elderly participants had a significant longer mean response time (1028 ms.) than the middle-aged (505 ms.), children (340 ms.) or young adults (223 ms.). Second, the participants showed a longer response time at the post-error trials (542 ms.) in comparison with the post-correct trials (506 ms.), confirming PES, $F(1,60)= 10.22$, $p<.01$). Third, no interaction effect was found between trial and age group. Last, response times also decreased across key presses (key 1: 668 ms. to key 6: 440 ms.), $F(5,300)=12.25$, $p < .001$).

SS for the 3-key sequences

Then, an ANOVA was performed to see whether SS differed significantly for the four age groups in the 3-key sequences. It was applied to trial (2: repetition vs. alternation), block (6: 1 to 6), and key position within the key (2: 3-key or 6-key) as within-subject variables and age group (4: children, young adults, middle-aged and elderly people) as between-subject variable. All participants were included in the data.

First, results showed that there was a main effect of age, $F(3,92)=40.66$, $p<.001$), whereby the elderly participants had a significant longer mean response time (1020 ms.) than the middle-aged (543 ms.), children (428 ms.) or young adults (291 ms.). Second, the participants showed a longer response time at the alternation trials (576 ms.) in comparison with the repetition trials (565 ms.), confirming SS, $F(1,92)= 5.57$, $p<.05$). Third, an interaction effect was found between trial and age group, whereby all age groups, except the young adults, demonstrated a longer response time at the alternation trials in comparison with the repetition trials, $F(3,92)=2.72$, $p<.05$), see figure 3.

Figure 3: *Mean response times for the response repetition and response alternation 3-key sequences as a function of age group*



The elderly participants displayed the largest delay (25 ms.), followed by the children (14 ms.) and the middle-aged people (12 ms.). The young adults had a negative delay (-10 ms.). Fourth, response times also decreased across blocks (block 1: 712 ms. to block 6: 506 ms.), $F(5,460)=73.75$, $p<.001$) and key presses (key 1: 643 ms. to key 3: 505 ms.), $F(2,184)=35.27$, $p < .001$). Last, further interaction effects were found for key and age group $F(6,184)=3.8$, $p < .001$), block and key $F(10,920)=25.56$, $p < .001$), and block, key and age group $F(30,920)=3.07$, $p < .001$).

SS for the 6-key sequences

Finally, an ANOVA was performed to see whether SS differed significantly for the four age groups in the 6-key sequences. It was applied to trial (2: repetition vs. alternation), block (6: 1 to 6), and key position within the key (2: 3-key or 6-key) as within-subject variables and age group (4: children, young adults, middle-aged and elderly people) as between-subject variable. Two participants were not included in the analysis (see table 5), because their data was incomplete.

Table 5: *Participants in the SS 6-key sequences*

Age group	N
Children	24
Young adults	24
Middle aged	24
Elderly	22

First, results showed a main effect of age, $F(3,90)=41.14$, $p<.001$), whereby the elderly participants had a significant longer mean response time (1056 ms.) than the middle-aged (543 ms.), children (422 ms.) or young adults (289 ms.). Second, the participants showed a significant shorter response time at the alternation trials (571 ms.) in comparison with the repetition trials (584 ms.), $F(1,90)= 15.9$, $p<.001$). Third, no interaction effect was found between trial and age group. Fourth, response times also decreased across blocks (block 1: 753 ms. to block 6: 490 ms.), $F(5,450)=117.6$, $p <.001$) and key presses (key 1: 666 ms. to key 6: 525 ms.), $F(5,450)=17.82$, $p < .001$). Last, interaction effects were found between block and age group, $F(15,450)=2.04$, $p<.05$), key and age group, $F(15,450)=5.84$, $p<.001$), trial and key, $F(5,450)=4.52$, $p<.01$), block and key, $F(25,2250)=9.43$, $p<.001$), block, key and age group, $F(75,2250)=1.89$, $p<.001$), trial, block and key, $F(25,2250)=1.93$, $p<.01$), and trial, block, key and age group, $F(75,2250)=1.38$, $p<.05$).

Conclusion & Discussion

This study examined the differences in motor sequence learning for four age groups. Hereby two mechanisms were studied; post-error sequence slowing (PES) and sequence switching (SS).

PES was confirmed for both the short and long sequences. However, only at the short sequences the U-shaped form of PES (Kramer et al., 1994; Bedard et al., 2002; as cited in Gupta et al., 2009), was significantly shown between the age groups. At the long sequences, and both the sixth blocks of the 3-key and 6-key sequences, no significant differences were found for PES between the age groups. Again, with respect to SS, it was confirmed for the short and the long sequences, but it only showed an U-shaped form (Cepeda et al., 2001) at the short sequences, not at the long sequences. Strikingly, in the latter the effect was reversed, whereby the participants had a shorter response time at the alternation trials, in contrast to the repetition trials. However, this is in line with the work of Crone et al. (2006), who stated that when responses are repeated the response time costs are larger when responses are alternated.

It is noteworthy that both PES and SS showed the same pattern in the two sequences, whereby for the 3-key sequences there were significant differences between the age groups, but for the 6-key sequences there were not. It may have something to do with working memory. Working memory, as stated by Norman (2013), is the link between the input of the senses and long-term memory, whereby there is a limit of maximal nine chunks of information that can be retained. The way in which the chunking in this study has occurred could be a possible explanation for the differences between the short and long sequences of PES and SS, for the change of sequences into motor chunks across sets is more likely when each set-size is lower (Pammi, Miyapuram, Bapi & Doya, 2004). As a result, it is possible that chunking has occurred more in the 3-key sequences, and therefore PES and SS have been seen significantly between groups. Additionally, there were more participants included in the analysis of the 3-key sequences (PES: N=44, SS: N=96), compared to the analysis of the 6-key sequences (PES: N=29, SS=94). This could have enhanced the effect. However, Cepada et al. (2001) stated that the performance in task-switching between ages is independent from cognitive processes as working memory. Therefore, further investigation is needed in order to clarify the role of working memory in chunking.

The purpose of this study was to examine PES and SS which are present during learning and performance of discrete movement sequences over the lifespan. In conclusion, it is stated that both PES and SS showed an U-shaped form in their development over the lifespan, but only at the short sequences. Hereby limitations were the validity and reliability of the PES data. Some of the participants, especially the young adults and the middle-aged participants, did not make errors during their sequences. Therefore, their reaction times were not included in the analysis. Consequently, the limited number of participants in the analysis caused a low power, and therefore an inability to draw reliable conclusions. Future research should include a larger sample, and should focus on sequences longer than three key presses, to discover their development over the lifespan and their underlying cognitive processes.

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