THE EFFECT OF VERBAL LEARNING ON THE SEGMENTATION OF KEYING SEQUENCES

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Abstract

The aim of the study was to determine whether verbal learning determines later motor chunks. Twenty-four participants were divided into two groups wherein the verbally learned letter series differed. Both groups executed a discrete sequence production (DSP) task with two phases. The practice phase included six identical blocks with two letter sequences, and the test phase contained three different test conditions: familiar letter sequences, a reversed combination of familiar verbally learned letter segments, and letter sequences with new segments. The analysis of the practice phase revealed a concatenation point on the fourth key for both groups, meaning that the participants of both groups used the same segmentation of the letter sequences. This concatenation point almost completely disappeared over the course of the other blocks in the practice phase, which indicates the acquisition of a motor chunk for the entire letter sequences. The analysis of the test phase revealed that the performance of both groups in the test conditions was largely the same, which means that there was no effect of the existing verbal chunks on the acquired motor chunks.

Samenvatting

Het doel van deze studie was om vast te stellen of verbal chunks latere motor chunks bepalen. Vierentwintig participanten waren verdeeld in twee groepen, waarin de geleerde verbale letterseries verschilden. Beide groepen voerden een discrete sequence production (DSP) taak uit die uit twee fases bestond. De oefenfase bestond uit zes identieke blokken met twee letterreeksen en de testfase bestond uit drie verschillende testcondities, namelijk: de bekende letterreeksen, een omgekeerde combinatie van de bekende verbaal geleerde lettersegmenten en letterreeksen bestaande uit nieuwe segmenten. Uit de analyse van de praktijkfase kwam naar voren dat het concatenatiepunt bij beide groepen op de vierde toets lag. Dit wijst erop dat de participanten van beide groepen dezelfde manier van segmentatie toepassen op beide letterreeksen. Het concatenatiepunt verdwijnt bijna geheel na het uitvoeren van de latere blokken in de praktijkfase. Wat betekent dat de verworven motor chunk bestaat uit de hele letterreeks. Uit de anlayse van de testfase blijkt dat de uitvoering van beide groepen bijna gelijk was. Hieruit kunnen we concluderen dat er geen effect was van de verbale chunks op de verworven motor chunks.

Introduction

Nearly all the actions we perform in daily life are learned and memorized. As a preschooler in Dutch schools, children learn to tie their shoelaces. At home they practice with their parents over and over again until they know it by heart. With ongoing practice in the following years, children tie their shoelaces faster and faster until they can do it automatically without thinking how it has to be done. Since then the movement is a part of their everyday life. Another example of memorizing is when a person needs to remember a telephone number, e.g., 07636945978. It would be convenient for the person to group the digits into small parts to recall the series of numbers later as a whole. In this case, the person could group the number as follows: 076 369 459 78.

To simplify the learning process of a new task (e.g. tying shoelaces, memorizing a phone number) persons split this process in multiple actions or chunks. According to Gobet et al. (2001) 'chunking' is an information-processing mechanism which collects a number of pieces of information from the environment, or actions, into a single unit. Chunking is traditionally often conceptualized by reference to the recall of verbal lists, such as a phone number (Gilbert, Boucher, & Jemel, 2015). Because a memorized phone number is a list of verbally memorized numbers, is it called a verbal chunk.

The ability to learn new action sequences (e.g. tying one's shoelaces) is fundamental for everyday motor behaviors. Most of the motor actions people perform in daily life consists of series of relatively simple movements that are executed in a specific order (Ruitenberg, Verwey, Schutter, & Abrahamse, 2014). The example of tying one's shoelaces indicates a motor sequence which refers to the acquisition of the skill to rapidly and accurately produce a sequence of movements with limited effort and attentional monitoring (Abrahamse, Ruitenberg, De Kleine, & Verwey, 2013). According to Abrahamse et al., (2013) such learning is typically based on repeated practice and explicit instruction, explicit trial-and-error discovery and implicit detection of regularity. The short series of movements are performed repeatedly in close temporal proximity. These series of movements are assumed to gradually integrate into a single representation, the 'motor chunk' (Abrahamse et al., 2013). Motor chunks are the memory representations that allow familiar movement sequences to be selected and execution as a single response (Verwey, 1999; Verwey, Abrahamse, & Jiménez, 2009). Once a task is learned, a single representation (i.e., a motor chunk) for the task can be stored in, and retrieved from, long-term memory (Bo, Jennett, & Seidler, 2011).

Chunks and memory

In everyday life, speech involves rapid series of connected sounds. Listeners need to buffer incoming sequences in working memory (WM) in order to interpret these changing signals (Gilbert et al., 2015). Since WM is limited, sequential information (e.g., a phone number) is segmented into verbal chunks that will fit in WM. Although the capacity of working memory is limited, large numbers of digits can be learned if they are chopped up in chunks before being stored in long-term memory (LTM).

According to the Dual Processor Model (DPM) a cognitive and a motor processor assumed to be responsible for skill in executing short (i.e., discrete) movement sequences (Abrahamse et al., 2013). During early practice of a new movement sequence, the cognitive processor translates each externally presented stimulus into the associated response, and prompts the motor processor to execute this response. When the movement sequence is relatively novel but sequences are explicitly known (e.g., verbal instruction about how to tie shoelaces), a limited number of individual responses may also be loaded, one by one and before execution, into the motor buffer. If the central (cognitive) processor is not occupied by another task it can speed up execution by triggering, in parallel to the motor processor, the individual responses on the basis of stimuli (Verwey, 2001, 2003, 2015), or cognitive sequence representations (Ruitenberg et al, 2012; Verwey, 2015). According to the DPM a distinction can being made between an external execution mode and an internal execution mode (Verwey, 2001). The external execution mode involves guidance of movement sequences by the central processor reacting to element-specific stimuli (Hikosaka et al., 1999; Tubau, Hommel, & López-Moliner, 2007; Verwey, 2015). This external control involves a reaction mode and an associative mode. In the reaction mode, series of movements are executed by merely reacting to successive stimuli. However, when a movement sequence is executed over and over again, the sequence may continue to involve reacting to stimuli while processes and representations required for each response also are gradually primed by the processes used to produce earlier responses. This way of producing movement is called the associative mode (Verwey & Abrahamse, 2012; Verwey, 2015).

As short series of movements are repeatedly executed in close temporal proximity, these series are assumed to gradually integrate into a single representation, the motor chunk (Abrahamse et al., 2013). In the case of the internal sequence control, it is assumed that each individual movement is selected on the basis of a motor chunk (Verwey, 2015). The central processor selects and loads the movement representations into a short-term motor buffer, which is assumed to be a part of the working memory (Smyth and Pendleton, 1989;Tattersall and Broadbent, 1991; Verwey, 1999, 2015). The movement representations are loaded either one by one, or on the basis of an integrated representation (i.e., a motor chunk), such as tying one's shoelaces (Verwey, 1996, 2015). The use of these motor chunks is referred to as the chunking mode (Verwey, 2003, 2015; Verwey, Abrahamse, Ruitenberg, Jiménez, & De Kleine, 2011). The availability of motor chunks allows the cognitive processor to eventually select and load this motor chunk from long term memory in a single processing step into the motor buffer, as if each motor chunk constitutes a single response (Verwey, 1999; Abrahamse et al., 2013).

The discrete sequence production (DSP) task developed by Verwey (2001) is a way to study the development of motor chunks. According to Abrahamse et al. (2013) the aim of the DSP research is to explore the creation and exploitation of newly acquired sequence representations that eventually lead to the development of motor chunks. The DSP task of Verwey (2001) involves a test setting where participants rest four to eight fingers on the indicated keys of the keyboard, depending on the presented number of stimuli that the sequence contained. There is a similar number of small squares displayed on the computer screen which correspond to one of the indicated keys of the keyboard (Abrahamse et al., 2013). A typical DSP sequence involves two fixed series of 3-7 stimuli which results in an execution of two equally long key-press in a random order. A motor chunk is developed when, for example, two different 6-key sequences turn with practice, from two series of 6-choice Reaction Time (RT) tasks, into a single 2-choice RT task in which an entire 6-key sequence constitutes a single responses. The DSP task usually starts off with a practice phase to develop the motor chunks, and is continued with a test phase in which a novel (unfamiliar) sequences are taken as control condition (Abrahamse et al., 2013). In the DSP task of the present study S1 was used to indicate the stimulus of a sequence, R_n to indicate the n-th response in the sequence, and K_n to indicate the RT associated with S_n.

According to Abrahamse et al. (2013) the overall execution of a well-learned keying sequence can be related to three distinct processing phases that are reflected in the respective RTs. The first processing phase of learning a sequence is the *initiation phase* (K1) (as shown in figure 1). The initiation phase is assumed to involve the selection and preparation of the sequence. The first key-press of a letter sequence is typically much slower than the subsequent key-presses, which is caused by the anticipation to the presentation of the stimulus (S1) as is shown in Figure 1. The key-presses following sequence initiation are very fast. Sometimes with RTs below 100 ms, which is possible because they involve just execution processes (Abrahamse et al., 2013). Together, these key-presses are referred to as the *execution phase* (see Figure 1). Verwey and Eikelboom (2003) argued that longer, fixed sequences are divided into multiple motor chunks due to assumed limitations in the length of a single motor chunk. Abrahamse et al. (2013) suggested that most participants executed a 6-key sequence as 2 or more successive segments. Such segmentation between 2 or more successive motor chunks is referred to as the *concatenation phase*. The concatenation point (as shown in Figure 1) is the relatively slow response halfway through the keying sequence, which is assumed to index the transition from one motor chunk to the next (Abrahamse et al., 2013).

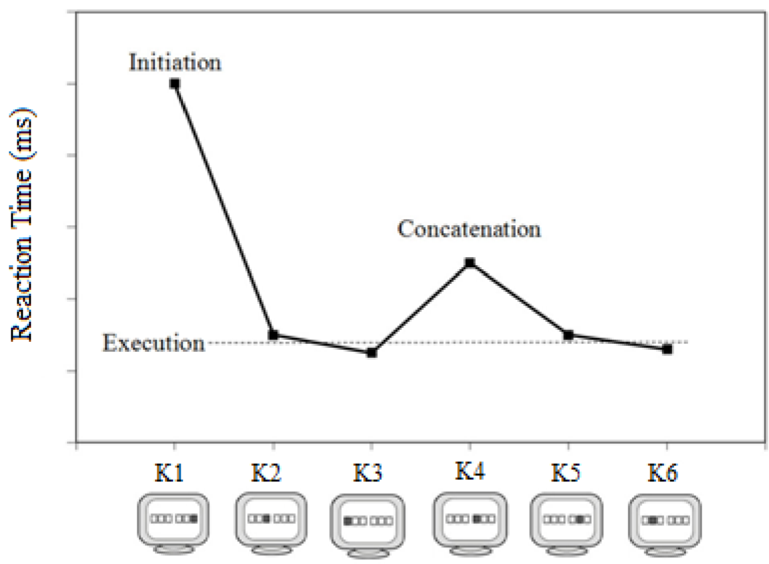


FIGURE 1 | Execution of a 6-key sequence and its reaction time pattern. It consists the processing phases: initiation, concatenation, and execution.

The present study

In the present study we have tested whether verbal chunking determines later motor chunks. The participants of the study were divided into two groups. The first group verbally learned four letter series of three letters, and the second group verbally learned two series of two letters, and two series of four letters (see Appendix A). The participants were tested in order to investigate whether the participants had developed verbal chunks of the verbally learned letter series. The DSP task was used to test the acquisition of motor chunks. This task was divided into a practice phase and a test phase. The practice phase was used to acquire motor chunks of two different letter sequences. In this phase we tested whether the concatenation point of the first group is on the fourth key (the first letter of the second letter series) and whether this concatenation point will develop at the third or the fifth letter (the first letter of the second letter series) in the second group. For example, if the first participant acquired four verbal chunks of the four letter series of three letters each, and these letter series were used in the DSP task as two letter sequences with two letter chunks each, the reaction time would be higher on the fourth letter (the concatenation point). The question is whether this concatenation point would develop at another key if the second participant learned different verbal chunks than the first participant. This participant had acquired two verbal chunks of two letters and two verbal chunks of four letters of the four letter series. The participant also got two letter sequences with two chunks, however these chunks were build up different than the first participant. If the first participant had abc-def and fdb-cae, the second participant could have had ab-cdef and fdbc-ac. The concatenation point might be developed at the third or the fifth letter. In short, we wanted to investigate whether the concatenation point of the keys corresponds with the learned verbal letter series, the acquired verbal chunks.

In the test phase we determined whether the performance of the two groups of participants in the test conditions, between the familiar learned letter series and unfamiliar letter series, were different. The familiar learned letter series were acquired as a motor chunk before the start of the DSP task, and were practiced in the practice phase. We predicted that the reaction times of the given new letter sequences were slower than the reaction times of the familiar letter series (i.e., the practiced combinations of the practice phase, and the reversed combinations of the familiar letter series in the test phase). What was also expected that there are no concatenation points in the letter sequences with new letter series, because the participants did not acquire verbal chunks of these unfamiliar letter series. Hereby we can ascertain whether verbal chunks have effect on the acquirement of motor chunks.

Methods

Participants

Twenty-four undergraduate students took part in this experiment (average age of 22.6, range 18-34 years; 16 women). A large part of the participants took part in this experiment in exchange for course credits. They were randomly assigned to one of the two groups with 12 participants per condition. The study was approved by the ethics committee of Faculty of Behavioural, Management, and Social Sciences of the University of Twente.

Apparatus

The experiment was carried out on a computer with Windows 7 Enterprise as operating system. Unnecessary Windows services were shut down to improve RT measurement accuracy. Stimuli were presented on a 22 inch LG Flatron E2210 display set at a resolution of 1680 by 1050, in 32 bit color, and refreshing at 60 hz. The viewing distance was approximately 50 cm, however this was not strictly controlled. The E-prime© 2.0 experimental software package was used for stimulus presentation, timing, and data collection. For the verbal test a headphone was used with a microphone for audio recording.

Tasks

The experiment included three tests, the verbal test, the DSP task and the awareness test. The participants were divided into two groups. The first group (Group 33) verbally learned in advance of the experiment four letter series, which consisted of three letters each. The second group (Group 242) learned also four letter series in advance, however these consisted of two chunks of two letters and two chunks of four letters. As an example, participants 1 and 7 learned gtc pdb tgb dpc, and participants 13 and 19 learned gtcp db tg bdpc. The letters being used in the letter series were balanced among all the learned letter series of the participants. This means that four participants had the same letter sequences in the verbal chunks. The verbal chunks were the same by 8 participants, but the sequences of these learned chunks were different (e.g. gtc pdb tgb dpc, or tgb dpc gtc pdb). Balancing was also used in the letter sequences of the DSP task. It is likely that if all the letters of the to be executed letter sequences are fixed, the reaction time of the index finger could be faster than the reaction time of the little finger. This means that always one letter has the slowest reaction time. To prevent this, we gave the participants different combinations of the letter sequences (see Appendix A).

Verbal test

The verbal test was used at the beginning and at the end of the experiment. The computer screen displayed a stimulus, the first letter of one of the four verbally learned letter series. From the moment the letter was displayed, the participants had 3 seconds to verbalize the indicated letter series clearly and rapidly, after which a black cross was displayed, which indicated the start of a new audio recording. Every first letter of a letter series was displayed three times one by one, and in a randomized order. The verbalized letter series were one by one recorded as one audio recording file. These data is not reported in this thesis.

DSP task

The DSP task consisted of two phases, the practice phase and the test phase. The practice phase was composed of 6 practice blocks. Six black placeholders were presented horizontally in the center of the screen against a white background. There was a little space between the placeholders to mimic the positions of the response keys on the keyboard (as shown in Figure 2). The participants were instructed to lay their ring, middle, and index fingers on certain keys on the keyboard. The three fingers of the left hand respectively on the keys D, F, G, and the three fingers of the right hand respectively on de keys J, K, and L.

As indicated in Figure 2, the keys on the keyboard did not match with the given letter sequences. This way participants who were able to type blind were supposed to have no advantage over participants who could not. Thus all the participants had to learn which given letter of the letter sequence corresponds with a key of the keyboard. The stimulus was the given letter sequence the participants had to type. If a wrong key had been pressed an error message appeared, and was followed by the next sequence.

As shown in Figure 2, in each practice block a fixation stimulus (six crosses on the spot of the letter sequence) was shown. This was the cue that the first letter sequence of the block would appear. Next, the stimuli (i.e., one of the two fixed letter sequences) were presented, which required six key responses (R_1-R_6) for each fixed letter series. The reaction time between stimulus *n* and response *n* is indicated by K_n. A practice block contained two parts with two 6-key sequences, presented in random order. Between the two parts of each block was a break of 40 seconds, and between the blocks a 180 seconds break. Each block contained 74 trials per letter sequence. Participants executed 148 trials for two letter sequences. Thus participants executed in 6 block a total of 888 trials, 444 trials per keying sequence (i.e., 74*2*6=888). The two letter sequences in block 1 were repeated in all the practice blocks.

In the test phase, or block 7 of the DSP task, participants were tested in three sub parts, all three sub parts consisted of two different letter sequences, given in randomized order. One part had two familiar sequences, and consisted of the verbally learned letter series, which had been practiced in the 6 practice blocks. The second and the third part of the test block contained different letter sequences. The second part contained two letter sequences with new combinations of the familiar verbally learned letter series, and the third part contained letter sequences of unfamiliar letter series. Every sub part consisted of 20 trials per letter sequence, which means that there was a total of 120 trials (2x20x3=120 trials) in the test phase. Between the sub parts was likewise a break of 40 seconds.

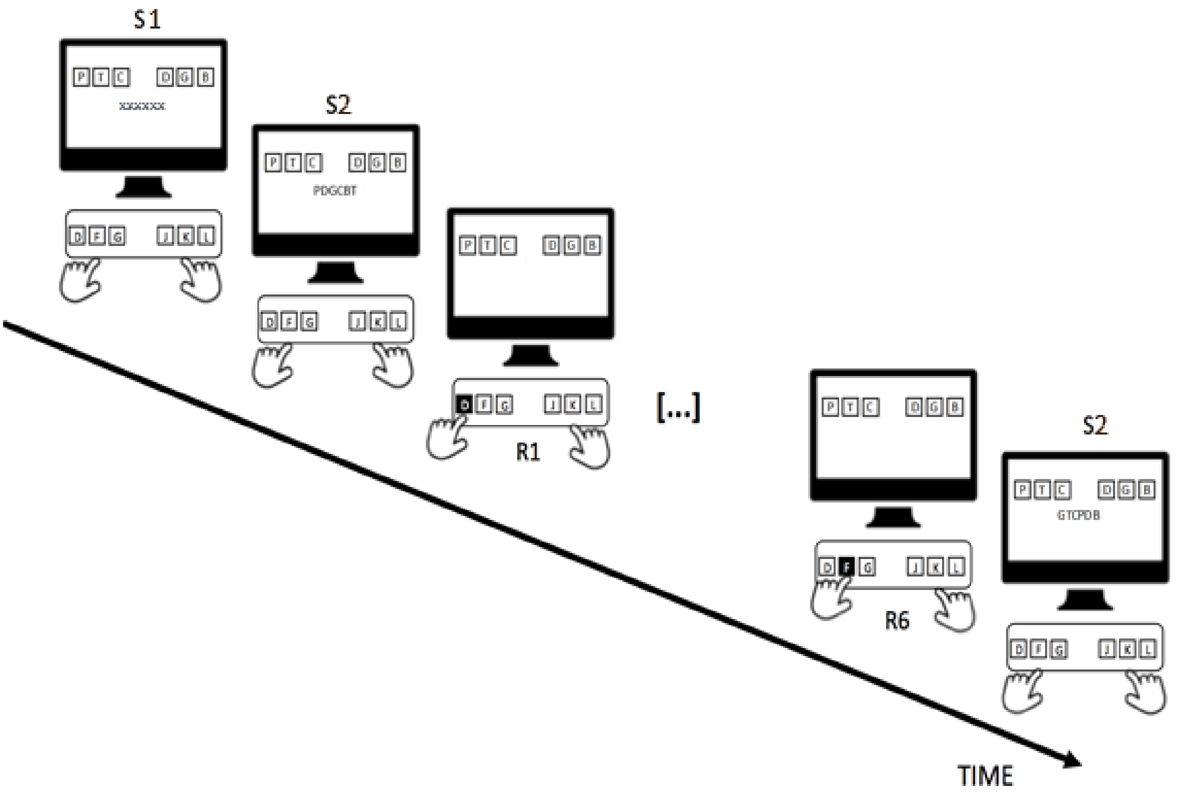


Figure 2 | Execution of the DSP task used in this study.
At the start of a block, a fixation cue, six crosses on the place of the next letter sequence, appeared (S1). Then one letter sequence (S2) was presented. The participant typed the letter sequence in the given order. Participants pressed six keys (R_1-R_6) to this stimulus if the typed letter sequence was correct.

Awareness test

The Awareness test was executed right after the practice phase (i.e., before the test phase). This test consisted of two tasks given in a balanced order to the participants to make sure that there was no order effect. The two tasks were used to test either the spatial, or the verbal sequential knowledge. Before the test was started, the keyboard was turned upside down to make sure the participants could not use or see the keys of the keyboard. The spatial representation was tested by squares in a row representative to the six used keys of the keyboard and the six placeholders on the computer screen used in the practice phase. No letters were indicated. The participants were asked to click on the specific square which would be the position of a letter of the letter sequence, starting with the first letter of the letter sequence. The verbal representation was tested by six squares arranged in a circle which contained each a letter. Participants were asked to click on the letter squares in the same order as they would type the letter sequence. The participants executed each of the two tasks twice, for every learned letter sequence in the practice phase once. After both tasks, participants were asked to answer a short questionnaire about the tasks. The participants were asked to indicate which method they had used to recall their letter sequences: by a) remembering the order of the letters on the keys, b) tapping the sequences on the table top, c) tapping the sequences in their mind, d) remembering the positions of the stimuli and keys, and e) did not had a clue and just guessed it. The last question was if the participants were sure about the indicated series: by a) very unsure, b) a little bit unsure, c) a little bit sure, and d) very sure. These data will not be reported in this thesis.

Procedure

A couple of days before the start of the experiment participants were asked to memorize four letter series at home. The participants were informed they would have to enumerate the letter series without mistakes. At the start of the experiment the participants had to prove that they memorized the letter series with a short verbal examination. Provided that the participants' had memorized the letter series well, they were allowed to start the verbal test. Otherwise the participants were asked to leave the experiment. At the start of the verbal test participants were asked to put on a headphone with a microphone to record their verbal responses.

After the verbal test, the practice phase of the DSP task was launched. Before the first block of the practice phase was started, information about the process of the test was shown on the computer screen. Herein was stated (in Dutch): 1. There are six letters displayed below the placeholders. Please memorize these, because at the first keypress they will disappear. Press as fast as possible on the given keys (without making mistakes). 2. Now put your fingers on the indicated keys: left ring, middle and forefinger on the keys left of H (dfg) and the right ring, middle and forefinger on the keys right of H (jkl). 3. Please leave your fingers on the indicated keys.

After every part of a practice block, the percentage of mistakes and the average reaction time of the participants were shown. Furthermore the countdown of the break in seconds was shown. The letters in the placeholder were fixed, which means that these letters where shown during the whole DSP task. The six placeholders were a graphical representation corresponding with the keys on the keyboard.

After the practice phase of the DSP task, the awareness test took place, in which the participants reproduced the sequences of the DSP task, by clicking on squares in two different ways. Subsequently all participants performed the test block of the DSP task. It took a participant on average two and a half hours to complete the experiment.

Results

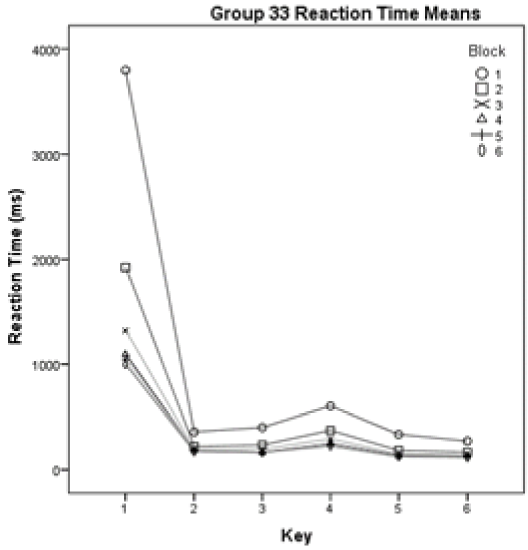
Practice phase

Reaction times

The development of keying skill in the practice phase was examined with a 2 (Group: 33 vs. 242) x 2 (Segment 2433 vs. 4233) x 6 (Block) x 6 (Key: R_1-R_6) repeated measures ANOVA with Group as between-subjects variable. It showed main effects of Block, $F(5,110) = 93.9$, $p <.001$, $\eta p^2 = 0.81$, and Key, $F(5,110) = 107.3$, $p < 0.001$, $\eta p^2 = 0.83$. These effects confirmed an overall difference in reaction times over the Blocks, as well as the main effect of Key. There was no significant difference between group 33 and 242 with respect to reaction times on key presses per block. This is indicated by Key x Block x Group, $F(25,550) = 0.5$, $p = 0.975$, $\eta p^2 = 0.02$. Figure 3 indicates that the concatenation point lied on Key 4 in group 33 as well in group 242, although the concatenation point was more flattened in group 242. Also can be derived from the figure that in both groups the first block contained the highest concatenation point on the fourth key in comparison with the blocks 2-6, and disappeared mostly in block 5 and block 6. As shown in Figure 3, there were some differences between the reaction time of the two letter sequences in group 242. As already stated, letter sequences contained two letter series. The letter sequences of group 242 contained two letter series of differences sizes. The first letter sequence (Segment 42) consisted of one letter series of four letters and a letter series of two letters, whereas the second letter sequences (Segment 24) consisted of one letter series of two letters and one letter series of four letters. This was confirmed in an separate ANOVA of group 242 in a main effect of, Segment x Key, $F(5,55) = 2.5$, $p = 0.045$, $\eta p^2 = 0.05$. There were no differences in the reaction time of the two letter sequences in group 33, which was confirmed by a separate ANOVA of group 33, Segment x Key, $F(5,55) = 1.7$, $p=0.151$, $\eta p^2 = 0.13$. Therefore it is acceptable to not separate both letter sequences for analyzing the reaction times of the participants.

The practice phase was meant for motor chunk development. The concatenation point on the fourth key in both groups had almost entirely disappeared in block 6. Which means that the participants did not split the letter series of the letter sequences in two anymore for execution, and therefore can be assumed that both letter sequences had become one motor chunk.

Group 33



Group 242

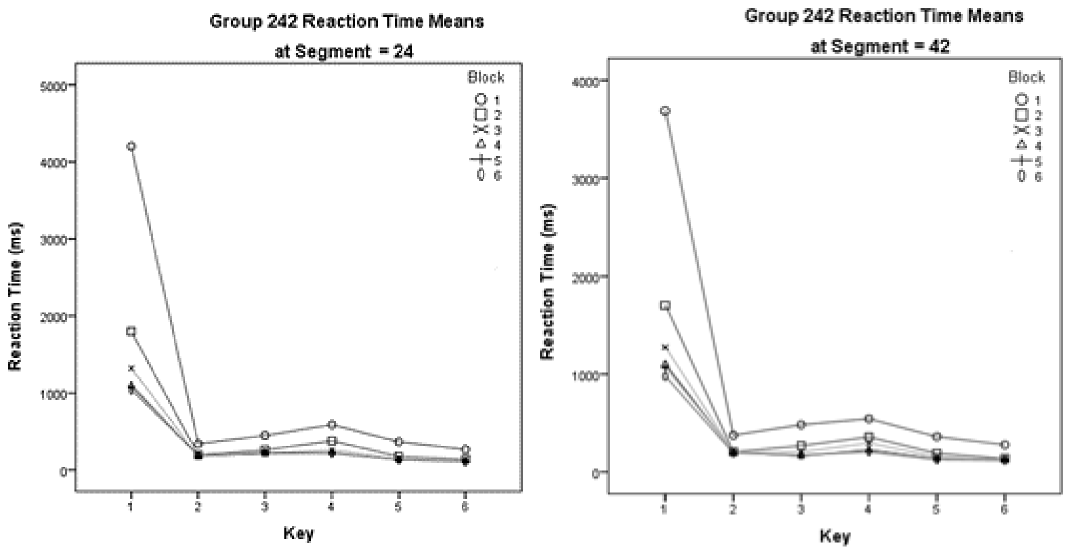


Figure 3 | Reaction times (ms) in group 33 and group 242 in the practice phase of the DSP task. There is in group 242 a distinction in the structure of the two letter sequences. Both the letter sequences are composed of two verbally learned letter series. The first letter sequence, segment 42 consists of a letter series with four letters, and a letter series with 2 letters. The second learned letter sequence consisted of the first letter series of 2 letters, and second letter series of 4 letters.

Error rate

The average proportion of errors was transformed with an arcsine function, analyzed by a repeated measures ANOVA, which is the same design ANOVA as was used in the reaction time analysis. The group main effect was not significant, $F(1,22) = 2.9$, $p = 0.101$, $\eta p^2 = 0.12$, indicating that there was no significant difference between group 33 and group 242 of the proportion errors. There was no significant difference in proportion of errors of the keys between the two given letter sequences as well, Segment x Key, $F(5,115) = 0.3$, $p = 0.919$, $\eta p^2 = 0.12$. The average error percentage of both groups on key 4 in block 1 was 9.9%, the highest error percentage of all keys in all the six blocks. The average error percentage was low, only 2.4% per key.

Test phase

Reaction Times

The reaction times in the test phase were examined with a 2 (Group 33 vs 242) x 2 (Segment 2433 vs. 4233) x 3 (Test Conditions: practiced, reversed, and new sequences) x 6 (Key: R_1-R_6) repeated measures ANOVA with Group as between-subjects variable. It showed main effects of Test Conditions, $F(2,44) = 86.1$, $p < 0.001$, $\eta p^2 = 0.80$, and Key, $F(5,110) = 262.1$, $p < 0.001$, $\eta p^2 = 0.92$. These effects confirmed an overall difference in reaction times over the test conditions, as well as the main effect of Key. Just as in the practice phase, the test phase showed no significant difference between groups 33 and 242 with respect to reaction times on key presses in the test conditions. This is indicated by Test Condition x Key x Group, $F(10,220) = 0.9$, $p = 0.567$, $\eta p^2 = 0.04$, (as shown in figure 4).

In group 33, there were no differences in the reaction time of the two letter sequences in the test conditions. This is confirmed by the, Segment x Key x Test Condition, interaction, $F(10,110) = 0.4$, $p = 0.963$, $\eta p^2 = 0.03$. In group 242 were no differences as well, Segment x Key x Test Condition $(10,110) = 0.9$, $p = 0.511$, $\eta p^2 = 0.08$. It can be derived from figure 4 that the concatenation points of both groups are the highest on the fourth key in the test condition with different letter series than the test condition with the familiar letter series. The concatenation point on the fourth key is in the familiar combination of practiced segments almost completely level.

It can be concluded that there is segmentation of letter series in the letter sequences with unfamiliar letter sequences with either familiar or unfamiliar segments. We can conclude as well that there are motor chunks acquired, due to the fact that the concatenation point of the familiar sequences were almost entirely flattened. Notable is that the reaction times of the test conditions of the reversed combination of familiar segments, and the new segments were almost similar in both groups (i.e., group 33 and group 242). Both the groups had a concatenation point on the fourth key. This means that the acquired verbal chunks were not used.

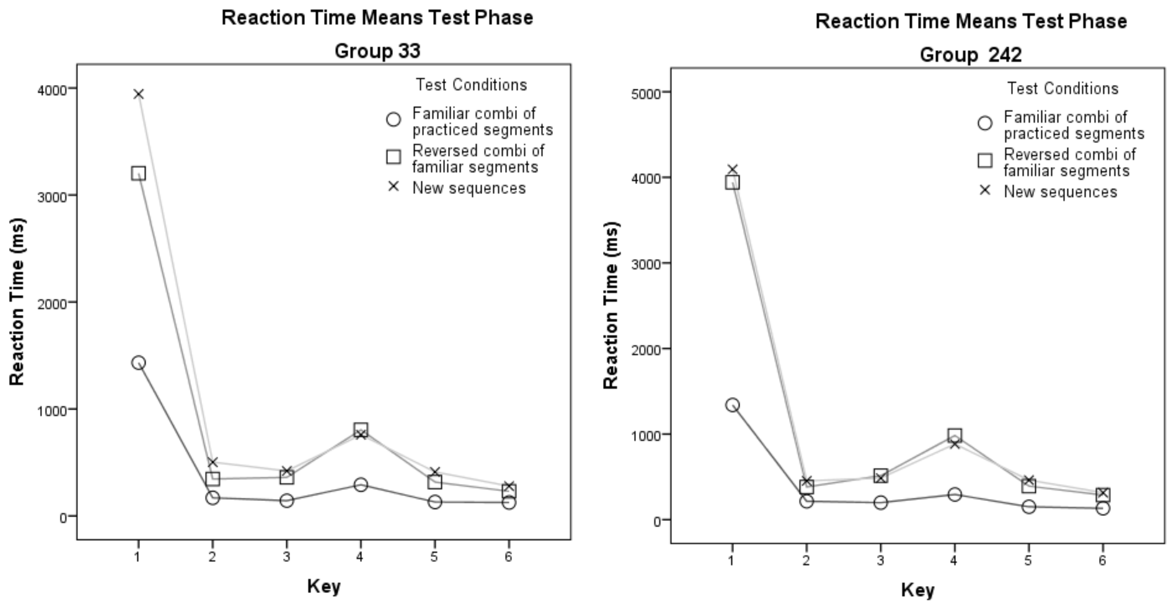


Figure 4 | Reaction times (ms) in group 33 and group 242 in the test phase of the DSP task. This figure showed that the concatenation points in both groups lies on the fourth key. These concatenation points are the highest in the test conditions of the reversed combination of familiar segments and new segments.

Error rate

The average proportion of errors in the test phase were transformed with an arcsine function. It was analyzed by a repeated measures of ANOVA, which is the same design ANOVA as was used in the analysis of the reaction times. The group main effect was significant, $F(1,22) = 8.2$, $p = 0.009$, $\eta p^2 = 0.27$, indicating that there was a significant difference between group 33 and group 242 in the proportion of errors. The error rates for Test Condition as for Key were also significantly different, Test Condition, $F(2,44) = 18.5$, $p < 0.001$, $\eta p^2 = 0.46$, and Key, $F(5,110) = 10.9$, $p < 0.001$, $\eta p^2 = 0.33$. There was a significant difference in proportion of errors of the keys between the two given letter sequences as well, Key x Segment, $F(5,110) = 7.3$, $p < 0.001$, $\eta p^2 = 0.25$. In all the test conditions, key 4 had the highest error rates. The test condition of the reversed combination of familiar segments had the highest average error percentage on key 4, 13.1%. The average error percentages of the familiar, and unfamiliar sequences with unfamiliar segments, were respectively 4.8%, and 12.7%. The average error percentage of the condition with familiar sequences was low, only 2.8%. The average error percentages of the unfamiliar letter sequences, with either familiar segments or unfamiliar segments, were both 6.1%.

Discussion

The purpose of the study was to investigate whether the motor chunks are determined by verbal chunks in a classical DSP task. Participants were divided into two groups wherein the four learned letter series (the acquired verbal chunks) differs. Group 33 had four letter series of three letters each, group 242 had two letter series of two letters, and two letter series of four letters. The study was firstly aimed to investigate the different reaction times of the two groups in the DSP task. The prediction was that the group of participants, that learned four letter series of three letters, would have a slower reaction time on the fourth key in the practice phase, as well in the familiar letter sequences of the test phase. Furthermore the group with the letter series of two and four letters would have a slower reaction time on either the third or the fifth key in the practice as well as in the familiar letter sequences of the test phase. It was predicted that the reaction times in the test phase of the given new letter segments were slower than the reaction times of the familiar letter series (i.e., the practiced combination of the practice phase, and the reversed combinations of the familiar letter series in the test phase). We expected that there are no concatenation points in the letter sequences with new segments, because the participants did not acquire verbal chunks of these unfamiliar segments.

We conclude that both groups had a concatenation point on the fourth key in the practice phase. This indicates that the participants of both groups used the same segmentation of the letter sequences. The concatenation point flattened with practice to a more or less flat line of reaction time per key. This means that, with practice of the letter sequences, the different letter series of these sequences should concatenate, and should become one motor chunk. Analysis of the test phase showed that the performance of both groups in the test conditions were mostly the same. This indicates that there was almost no difference between the versions of verbal learning.

We cannot conclude in the present study that verbal chunks determine later motor chunks. We have hypothesized that the learning curve is due to two factors, namely the order of the letter series in the motor chunk, and the order of the learned letters in the verbal chunk.

The awareness of the executed letter sequences could be different among the participants, due to the learning methods to execute the letter sequences among the participants. The question remains to which extent do participants use the verbal chunks to execute the letter sequences in the DSP task. Some participants may focus on the segment order of the letter sequences. Or they focus on the learned verbal chunk, and verbalize those segments. Also it is not clear to which extent the participants used the acquired verbal chunks when they verbalized segments of the given letter sequences on the computer screen. This verbalization could have been an aid to memorize the letter sequences. Hence, we have the presumption that the verbal chunks were not used in the DSP task. This might be due to the visual segmentation of the letter sequences on the screen. Both groups (i.e., group 33, and 242) visually segmented the letter sequence into two letter segments of three letters each. The placeholders where centered on the screen, meaning three blocks to the left of the middle and three blocks to the right from the middle of the screen. We suspect the segmentation of the letter sequences is due to this visual representation on the screen. The acquired verbal chunks of the verbally learned letter series might have a smaller stimulus on the participants compared with the visual grouping of placeholders. Future research could prevent the visual segmentation of the letter sequences by for example, the use of audio recordings of the letter sequences. By verbally stating the letter sequences, we think the participants will be more likely to use the acquired verbal chunks of the learned letter series.

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Appendix A Letter series

Old letter series (no replacement):

	verbal chunk as learned					practice & test: combi (3 then 3 segm)		test: new combinations of fam. segments		test: new sequences (R45 are fam.)	
Participant	ch1	ch2	ch3	ch4	ch5	DSP1	DSP 2	DSP 3	DSP 4	DSP 5	DSP 6
01 7	kfg	djl	fkl	jdg		A: kfg-djl	D: fkl-jdg	1:djl-fkl	4:jdg-kfg	B: lgj-fk-d	E: gld-kf-j
2 8	lgj	fkd	gld	kfj		B: lgj-fkd	E: gld-kfj	2:fkd-gld	5:kfj-lgj	C: djk-gl-f	F: jdf-lg-k
3 9	djk	glf	jdf	lgk		C: djk-glf	F: jdf-lgk	3:glf-jdf	6:lgk-djk	D: fkl-jd-g	A: kfg-dj-l
4 10	fkl	jdg	kfg	djl		D: fkl-jdg	A: kfg-djl	4:jdg-kfg	1:djl-fkl	E: gld-kf-j	B: lgj-fk-d
5 11	gld	kfj	lgj	fkd		E: gld-kfj	B: lgj-fkd	5:kfj-lgj	2:fkd-gld	F: jdf-lg-k	C: djk-gl-f
6 12	jdf	lgk	djk	glf		F: jdf-lgk	C: djk-glf	6:lgk-djk	3:glf-jdf	A: kfg-dj-l	D: fkl-jd-g

	verbal chunk as learned					practice & test: combi. (42 and 24 segm)		test: new combi. (24 and 42 segm.)		test: new sequences (R45 are fam.)	
Participant	ch1	ch2	ch3	ch4		DSP1	DSP2	DSP7	DSP8	DSP 5	DSP 6
13 19	kfgd	jl	fk	ljdg		A: kfgd-jl	D: fk-ljdg	a0:jl-kfgd	a1:ljdg-fk	B: lgj-fk-d	E: gld-kf-j
14 20	lgjf	kd	gl	dkfj		B: lgjf-kd	E: gl-dkfj	b0:kd-lgjf	b1:dkfj-gl	C: djk-gl-f	F: jdf-lg-k
15 21	djkg	lf	jd	flgk		C: djkg-lf	F: jd-flgk	c0:lf-djkg	c1:flgk-jd	D: fkl-jd-g	A: kfg-dj-l
16 22	fklj	dg	kf	gdjl		D: fklj-dg	A: kf-gdjl	d0:dg-fklj	d1:gdjl-kf	E: gld-kf-j	B: lgj-fk-d
17 23	gldk	fj	lg	jfkd		E: gldk-fj	B: lg-jfkd	e0:fj-gldk	e1:jfkd-lg	F: jdf-lg-k	C: djk-gl-f
18 24	jdfl	gk	dj	kglf		F: jdfl-gk	C: dj-kglf	f0:gk-jdfl	f1:kglf-dj	A: kfg-dj-l	D: fkl-jd-g

New letter series (after replacing letters):

NEW (after replacing letters):

	verbal chunk as learned					practice & test: combi (3 then 3 segm)		test: reversed combi of fam. segments		test: new sequences (R45 are fam.)=other's fam.	
Participant	ch1	ch2	ch3	ch4	ch5	DSP1	DSP 2	DSP 3	DSP 4	DSP 5	DSP 6
1 7	gtc	pdb	tgb	dpc		A: gtc-pdb	D: tgb-dpc	1:pdb-tgb	4:dpc-gtc	B: bcd-tg-p	E: cbp-gt-d
2 8	bcd	tgp	cbp	gtd		B: bcd-tgp	E: cbp-gtd	2:tgp-cbp	5:gtd-bcd	C: pdg-cb-t	F: dpt-bc-g
3 9	pdg	cbt	dpt	bcg		C: pdg-cbt	F: dpt-bcg	3:cbt-dpt	6:bcg-pdg	D: tgb-dp-c	A: gtc-pd-b
4 10	tgb	dpc	gtc	pdb		D: tgb-dpc	A: gtc-pdb	4:dpc-gtc	1:pdb-tgb	E: cbp-gt-d	B: bcd-tg-p
5 11	cbp	gtd	bcd	tgp		E: cbp-gtd	B: bcd-tgp	5:gtd-bcd	2:tgp-cbp	F: dpt-bc-g	C: pdg-cb-t
6 12	dpt	bcg	pdg	cbt		F: dpt-bcg	C: pdg-cbt	6:bcg-pdg	3:cbt-dpt	A: gtc-pd-b	D: tgb-dp-c

	verbal chunk as learned					practice & test: combi. (42 and 24 segm)		test: reversed combi of fam. segments		test: new sequences (R45 are fam.)=other's fam.	
Participant	ch1	ch2	ch3	ch4		DSP1	DSP2	DSP7	DSP8	DSP 5	DSP 6
13 19	gtcp	db	tg	bdpc		A: gtcp-db	D: tg-bdpc	a0:db-gtcp	a1:bdpc-tg	B: bcd-tg-p	E: cbp-gt-d
14 20	bcdt	gp	cb	pgtd		B: bcdt-gp	E: cb-pgtd	b0:gp-bcdt	b1:pgtd-cb	C: pdg-cb-t	F: dpt-bc-g
15 21	pdgc	bt	dp	tbcg		C: pdgc-bt	F: dp-tbcg	c0:bt-pdgc	c1:tbcg-dp	D: tgb-dp-c	A: gtc-pd-b
16 22	tgbd	pc	gt	cpdb		D: tgbd-pc	A: gt-cpdb	d0:pc-tgbd	d1:cpdb-gt	E: cbp-gt-d	B: bcd-tg-p
17 23	cbpg	td	bc	dtgp		E: cbpg-td	B: bc-dtgp	e0:td-cbpg	e1:dtgp-bc	F: dpt-bc-g	C: pdg-cb-t
18 24	dptb	cg	pd	gcbt		F: dptb-cg	C: pd-gcbt	f0:cg-dptb	f1:gcbt-pd	A: gtc-pd-b	D: tgb-dp-c