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Task integration in the Discrete-Sequence-Production-Task

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Abstract

A study was conducted in which 24 participants took part in a discrete sequence production task accompanied by a secondary tone counting task. Based on the Dual Processor Model the hypothesis was made that task integration is possible in the DSP-task. The participants learned to reproduce two sequences in six practice blocks. At the same time, half of the participants counted low pitched tones, the others ignored the low pitched and the high pitched tones. This was followed by a testing phase, where the secondary task condition (tone counting) changed because the tone was presented at a different point of the sequence. There was a condition with no tone, one condition with the tone on the third position just like in the practice phase and one condition with the tone on the fifth position. The results do not indicate task integration through suffering performance in the secondary task condition and therefore do not strengthen the position that task integration takes place through the cognitive processor.

Introduction

In our daily lives we engage in activities which show our capability of sequence learning and basic motor skill. We do not need to think about each movement we execute, but we are able to connect actions into sequences. According to Abrahamse, Ruitenberg, Kleine & Verwey (2013) motor sequence learning can be explained by the Dual Processor Model (DPM). The DPM is a cognitive model which assumes that there are two separate processors (Verwey, 2001). These two are the cognitive processor, which is responsible for higher level tasks and the motor processor, which is responsible for performing familiar motor behavior.

According to Abrahamse et al. (2013) sequences are divided into motor chunks, which are from three to five element long parts of longer sequences. The execution of these motor chunks is carried out by the motor processor. The cognitive processor uploads information about the motor chunks into the temporary motor buffer from which the motor processor takes the individual movements and use them to perform the sequence.

One important aspect of motor sequence learning is the construction of motor chunks through training. According to Abrahamse et al. (2013) motor sequence learning is involves repeated practice to induce trial-and-error discovery and more elaborated hypothesis testing. So, in the beginning of the task the sequence is executed consciously and the actions of the participant are basically reactions to the stimuli which are presented in the DSP-task. Through practice a motor representation of the sequence is generated and the physical sequence is split into cognitive motor chunks. If this training process has taken place, the cognitive processor is no longer responsible for searching the adequate response to the stimuli. According to Verwey (2010) the cognitive processor is after training still partly committed to the execution of motor chunks. It is not committed to the concatenation of two chunks, but it is active in each individual action. This leads to the question whether there is such a thing as cognitive sequence representation.

In the proposed model, the cognitive processor has a cognitive representation of the motor sequence (Verwey, Shea & Wright, 2015). Until now, there is just a notion that there is a cognitive representation about sequences. The cognitive processor is still committed to the task after uploading the information about the motor sequence, while no indication has been found that it is responsible for concatenating motor chunks (Verwey, 2010). We aim to discover more precisely, which role the cognitive processor plays in discrete sequence production.

The cognitive processor races with the motor processor, while carrying out sequences. While the sequences are carried out by the motor processor the cognitive processor is sometimes faster (Logan 1988; Verwey 2003; Verwey 2001). That means, that the cognitive processor reacts sometimes faster to the stimulus than the motor processor can execute the expected response from the motor chunk.

The question, which is investigated in this study is whether task integration is possible in motor sequence learning. Based on the assumption that motor chunks are developed after training we want to discover in what way the cognitive processor is still committed to the execution of motor chunks through making a cognitive representation of sequences. If the cognitive processor is committed to the execution of the DSP-task it may be possible that another task, which uses resources from the cognitive processor can be integrated in the execution of the sequence. If the cognitive processor is not committed to sequence production, changes in the task, which uses the cognitive processor, should not influence the performance in the primary task.

If there is a cognitive representation of motor sequences, tone counting may be become integrated into it. Tone counting does not influence the activity of the motor processor, so this activity would not be disturbed. If the cognitive processor engages in tone counting during the reproduction of a motor behavior sequence, counting the tone may become a part of the sequence representation. This is a specific form of task integration. According to Liepelt, Strobach, Frensch & Schubert, (2011) a general ability to inter-coordinate tasks can be developed through training. Combined with assumptions from the DPM (Verwey, 2001) this means that the two tasks are not carried out simultaneously, but integrated. While the cognitive processor is speeding up the sequence production it would integrate the primary task into the secondary task. So, the cognitive processor is carrying out both tasks as one because both tasks become one task through training. If the secondary task changed the performance in the primary task might suffer, because task integration could no longer take place.

To test this idea, the participants received the instruction to count tones, which appeared at a specific moment during the sequence. In the practice phase, the tone always appeared at the third sequential position. In the testing phase the tone was moved to another position. That may be a disturbance to the cognitive processor, which is active during the reproduction of the motor chunks. Through the appearance of the tone in another position the hypothetical cognitive representation of the chunk may no longer be useful. The cognitive processor "expects" the tone after one motor action, then it will wait for the tone to react to. This may result in a longer reaction time between those to responses, where the tone is expected.

The research question whether task integration takes place between a cognitive and a motoric task leads to the following hypothesis. If there is a change in the secondary tone counting task the performance in the primary sequencing task is affected by that.

This leads to these three predictions. First, the reaction times of the whole sequences should suffer, if the secondary task changes. So, we expected that the reaction times were slower if the tone is moved to the fifth position. The second prediction is, that the reaction time on key three is slower, if the tone is moved to the fifth position. The third and last hypothesis is that the reaction times are slower at key 5, if the tone is moved to the fifth position.

Methods

Participants

This study was conducted with 24 students from the University of Twente. They were recruited with help of the internal participant pool of the University In reward to participation the students (age ranging from 19 to 29, M = 21.542, thereof 23 right-handed, one left-handed) received three credit points, one for each hour respectively. The study was approved by the ethical commission of the University of Twente.

Apparatus

The E-prime © 2.1 experimental software package was used to present stimuli, guarantee timing and data collection. The presentation was conducted with the help of a Pentium© IV Windows XP© PC and a 17 inch Philips 107T5 LCD display (1024x768 pixel resolution, 32 bit color, 85 Hz). The uncontrolled viewing distance was about 70 cm. The audio signals were transmitted through over-the-ears headphones. A standard USB keyboard was used.

Procedure

Participants were instructed to fast and faultlessly perform the 7-key sequences. Then they signed a consent form before the experiment. Additional instructions were presented on the screen after the completion of six practice blocks, beginning with the instruction to place the fingers on four designated buttons and putting on the headphones. The participants were observed by video broadcast in a separate room.

The discrete sequence production and tone counting task

The discrete sequence production task was carried out by the participants and a tone counting task was added. The DSP-task consisted of two sequences, which the participants had to reproduce. Further the tone counting group had to distinguish two tones and count the low pitched tones. The control group ignored the tones while reproducing the sequences.

Participants put their left middle finger on the “c”-key, their left index finger on the “v”-key, their right index finger on the “b”-key and their right middle finger on the “n”-key. In the center of the computer screen the four keys were imitated with four horizontal arranged placeholders. Between the four placeholders there were 0.7 cm gaps.

The stimuli were presented by filling the first placeholder of the sequence on the screen with green. If the participant pressed the key associated with the placeholder on the screen the placeholder turned back to the background color and the following stimulus was presented the same way. This procedure went along, until the participant had reacted to all 7 stimuli of one sequence. Then there was an inter-trial-break of 1500 ms and the next sequence was presented. If a reaction of the participant was wrong the screen displayed “error” and the experiment continued with the next sequence.

During each sequence a tone was presented together with the third stimulus through on-ear headphones. The tone could be either high pitched (698 Hz) or low pitched (440 Hz) and was presented for 100 ms in the sequence. Participants in the experimental group had to count the low pitched tones and type in the number of them after each sub block.

Each sequence consisted of seven stimuli (S_1-S_7) and therefore there were seven responses (R_1-R_7). Each stimulus was presented directly after the previous response (except of S_1). The response time of each stimulus is the time between S_i and R_i and is called T_i.

Practice phase

The first 6 blocks of the experiment constituted the practice phase. Each of those blocks consisted of 240 trials i.e. sequences. It was randomly selected which of the two sequences was presented in each trial, but in the end the proportion was 50/50. Between each trial there was a break of 1500 ms. After the first 120 trials there was a break of 20 seconds and between the blocks there was a break of 4 minutes. In all of the breaks the participants in the experimental group had to type in the number of low pitched tones. Furthermore, statistics of the participant's performance were presented, namely the average reaction times and the error percentage added by the message "try less than 8%", the number of low pitched tones, and, if relevant how far the participant was off the mark.

Testing phase

The seventh block of the experiment was the testing phase. It consisted of three short sub-blocks instead of two long sub-blocks in the practice phase. The key sequencing task stayed the same but the tone condition differed. In one of the sub-blocks the tone was still presented together with S_3. In one condition the tone was switched to S_5 and in one condition there was no tone but the participants still had to wear the headphones. There were just the 20 second pauses between the sub blocks in the testing phase and the participants still had to report the number of low-pitched tones if they were in the tone counting condition. In the breaks, statistics were presented in the same way as in the practice phase.

Results

Practice phase

Reaction Time

The data was analyzed with a 6 (Block) x 7 (Key) x 2 (Pitch) x 2 (Group) mixed ANOVA with a Greenhouse-Geisser correction. The variable Group always served as between-subject variable while all other variable served as within-subject variable. It always is reported, if the Greenhouse-Geisser correction was necessary**.** The dependent variable was Response Time. All sequences in which an error occurred were not further analyzed for reaction time.

A significant effect of Block on Response Time was found, $F(5,110) = 200.85$, $p< .005$. This means that Reaction Time became faster during the practice phase. No significant interaction effect between Block and Group was found, $F(5,110) = 2.89$, $p = .059$. So, the Tone Counting group learned as well as the Control Group. The Pitch had no significant effect and no interaction with Group, $F(1,22) = .01$, $p = .0912$, $F(1,22) = 3.47$, $p = .076$. Also Key had a significant main effect, $F(6,132) = 79.517$, $p < .005$, what means that the Reaction Times differed across the Keys.

Errors

All participants stayed under 8 % error percentage per block and the overall error rate was $M = .018$ with a standard error of .002. To analyze the data about the errors a 6 (Block) x 7 (Key) x 2 (Pitch) x 2 (Group) mixed ANOVA with a Greenhouse-Geisser correction was conducted. Because the error data were not normal distributed an arcsine transformation was applied to the data, to improve the independence of the data. (Winer, Brown, & Michels, 1991). Significant effects on the error percentages were found in the independent variables Block ($F(5,110) = 3.695$, $p = .028$) and Key ($F(6,132) = 8.094$, $p < .005$). Also, an interaction of these two independent variables was significant ($F(30,660) = 4.693$, $p < 0.005$).

Testing phase

Reaction Time

The reaction times in the testing phase were analyzed with three ANOVAs. First, an analysis was done for comparison of the two tone pitches. The design was 2 (Position) x 2 (Pitch) x 7 (Key). The No Tone Condition was ignored in this analysis because we were interested in the change of the Tone Position. The No Tone Condition would distort the results. No significant effects were found but the effect of key, $F(6,132) = 77.754$, $p < .005$. An expected interaction effect of Group, Position, and Pitch was not significant ($F(1,22) = .188$, $p = .699$). Here we expected a slower Reaction Time in the Tone Counting Group if the Tone is placed to Position 5 in a low Pitch. In general, Pitch had no effect on reaction time, $F(1,22) = .151$, $p = .701$.

We continued with another repeated measures ANOVA with a Greenhouse-Geisser correction, this time with a 3 (Position) x 7 (Key) x 2 (Group) design. The high pitched (non – target) tones were ignored in this analysis and the independent variables were tone Position and Key. Just the trials with low pitched or no tones were taken into account. We expected to find an interaction between tone Position and Group, or between tone Position, Group and Key. The first effect was not significant, $F(2,44) = .379$, $p = .669$. That means again that there is no notion to accept our hypothesis. The second one was absent too, $F(12,264) = 1.713$, $p = .130$. Figure 1 shows the participant’s performance per block.

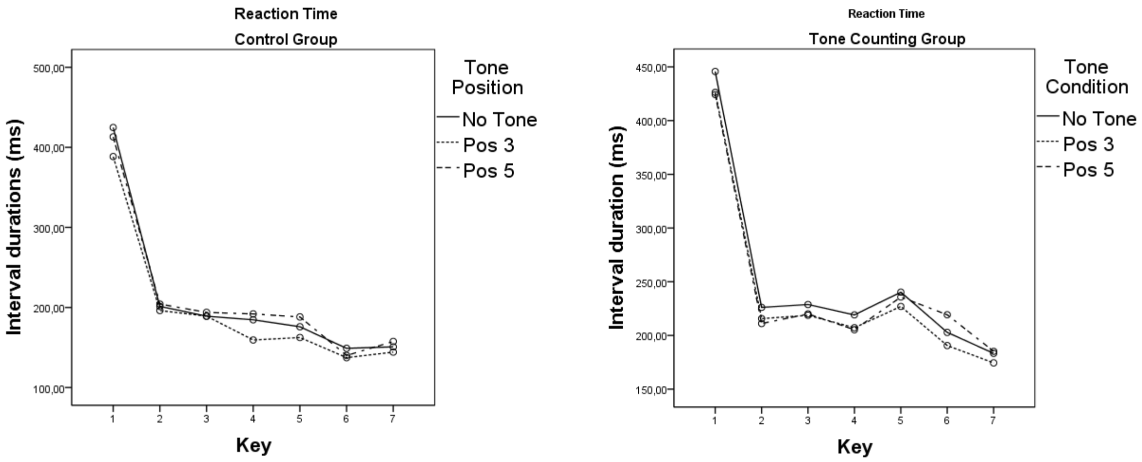

Figure 1: The figure on the left shows the Reaction Time of the control group, the figure on the right shows the Reaction Times of the tone counting group Practiced: Tone Position 3

The following ANOVA had the design 2 (Position) x 2 (Group) and just the reaction times on key 3 are taken into account. We analyzed whether the reaction times differed across the two Tone Positions. No significant effect was found, $F(1,22) = .407$, $p = .53$. The same design was used again, but this time we focused on key 5. Again, there was no significant effect, $F(1,22) = 1.747$, $p = .20$. This means, that we neither found a significant effect in the overall Reaction Time nor in the concerned Keys.

Errors

The design of the analysis of the error percentages was 3 (Tone Condition) x 7 (Key) x 2 (Group). The overall error quote in the testing phase was 1.9%. In the no tone condition it was 2.2%, in the standard tone condition 1.9% and in the late tone condition it was 1.7%. The differences were not significant. Only Key had a significant impact on the error percentages with $F(6,132) = 7.151$, $p < .005$.

Discussion

We wanted to find out, whether there is task integration of a motoric task and a cognitive task. The predictions were that the Reaction Time of whole sequences is slowed down in alternative tone condition, whether the Reaction Time is slowed down in some specific keys, and/or whether the reaction times were slowed down on key 3 or 5 in the alternative tone condition.

The overall Reaction Time did not become longer in changed secondary tasked conditions. No differences were found between the low Pitch condition and the high Pitch condition but we assumed that there is a higher cognitive workload in the low tone condition because in the low tone condition the participants identified the tone, counted it and remembered the number of low pitched tones, while they just identified the high Pitched tones. In consequence, just the low tone condition was taken into account for further analysis. Also, taking the high Pitched tone sequences into account could possibly influence the results, because conditions with lower cognitive workload could distort the data.

Rejecting our hypothesis the overall reaction times did not became slower in the condition, when the tone was switched to Position five. We proposed this hypothesis, because the DPM (Verwey et al, 2015) assumes that there is a cognitive representation of the motor sequence in addition to a motor chunk. This theory should go hand in hand with task integration, like it is defined by Liepelt, et al. (2011). So the tasks should be inter-coordinated and this takes place in the cognitive processor. So, the cognitive processor has several tasks at one time, which it carries out. The first are, as already mentioned, identifying, counting and remembering the low pitched tones and the other task is the primary task of selecting the next key for the sequencing task. If the cognitive processor were responsible for carrying out all of these tasks, there would be need for task integration. If task integration takes place, the two tasks are not just carried out simultaneous but they become more and more one task.

In consequence, the performance on the primary task (sequencing) should suffer if the conditions of the secondary task change. However, our results do not indicate this task integration, because there were no significantly slower reaction times in the changed secondary task condition.

Also, we wanted to find out whether the reaction times just became slower on specific parts of the sequence. Here the expected effect was also not significant. We also took a closer look on the keys three and five. But still the statistical analysis did not indicate slowed reaction times in the alternative secondary task condition.

From this we can conclude that the cognitive processor still was able to speed up the sequencing task, or that the cognitive processor is, against the assumptions of the DPM (Verwey, 2001), not committed in speeding up sequencing process. Slower reaction times were hypothesized because the cognitive processor was busy with the secondary task and therefore could not race with the motor processor for the decision, which key needed to be pressed. Obviously this was not the case in the setting of this experiment.

According to the Dual Processor Model this means that change in the secondary task condition maybe did not induce a higher load for the cognitive processor. So it still could speed up the process of sequence production. So, the cognitive processor did not play a big role in reproducing the keying sequences. Otherwise it is possible that the sequencing process is that much trained that the cognitive processor does not win the race with the motor processor. So giving it another task does not influence the acting of the motor processor in the primary task.

Conclusive, we found that task integration does not take place in the way we expected it. The C-SMB (Verwey et al, 2015) cannot fully explain the outcomes of this study in accordance with theory about task integration. It may be possible that the sequencing is speeded up by another process. This would mean that the DPM is no more able to explain serial motor behavior.

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