BACHELOR'S THESIS

EXPLORING THE DUAL PROCESSOR MODEL

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Contents

Exploring the dual processor model

Abstract

In this study we analysed the reaction times of 24 university students in a discrete sequence production task with a secondary tone counting task. After an extensive practice phase in which the participants automated the sequence production with the secondary task, the testing phase was conducted with two changed secondary task conditions. In the No Tone condition the secondary task was no longer present. This was done to see if the secondary task causes the segmentation of the movement sequence. The present results cannot confirm that the secondary task causes segmentation. The other changed condition had the location of the secondary task switched between the two sequences. This was done to see if task integration occurred with two clearly different tasks. The present results confirm this hypothesis. The results fit in a dual processing model of and are not compatible with a single resource model. The findings can be used for performance prediction in settings where highly automated processes occur.

Introduction

Currently the most common notion is that information is processed independently in the brain at the perceptual, cognitive and motor level (Anderson et al., 2004; Meyer & Kieras, 1997; Salvucci & Taatgen, 2008). However the details remain open for adaptation and interpretation and require more experimentation to fill them in. The current multi processor models vary on different processor roles to what extent a processor is responsible for a single process. In this study we examined sequence execution with a secondary task to test the impact of changed secondary task conditions. We are interested to see if the secondary task becomes integrated in the sequence under Verwey's model of dual processing (Verwey 2001).

Chunking

A chunk is said to develop because the working memory is limited in the amount of items it can process simultaneously. By putting several pieces of information together in a 'chunk', the mind counters this problem (Miller, 1956). A chunk then functions like a single item, resulting in the ability to handle more pieces of information. These chunks are limited in size and the size varies among individuals. Studies in working memory used highly practiced keying sequences and confirmed that extensive practice ultimately forms these chunks (e.g., (Van Mier & Hulstijn, 1993)

Dual processor model

Verwey proposed a theoretical model for the automatic execution of movement sequences (Rhodes, Bullock, Verwey, Averbeck, & Page, 2004; Verwey, 2001). A new unpractised movement sequence would be controlled by a cognitive processor selecting each part of the sequence separately. Highly practiced (automated) sets of movement, the so called motor chunks, are performed by the motor processor. In the event of longer automated sequences several chunks are executed after another. The dual processor model assumes that the cognitive processor performs this type of chunk sequencing (Verwey 2001).

The dual processor model assumes separate cognitive and motor processors because single processor models appeared to be unable to explain many results in the past (e.g., Meyer & Kieras, 1997; Verwey, 2001; Wickens, 1984). This assumption explains findings with concurrent processing where the execution rate goes down when the cognitive processor is occupied with a secondary task (Verwey 1995). A resource based model assumes that execution rate goes down because the overall cognitive load has increased. However the load of the secondary task itself appears to have no impact on the execution rate, which is not explainable with a resource based model (Jiménez & Vázquez, 2005).

The assumption is that the cognitive processor usually races with the motor processor to perform each response (Logan 1988; Verwey 2003; Verwey 2001). This makes sense because the cognitive processor had originally executed the sequence alone. The motor processor would be solely responsible for sequence execution only when the cognitive processor is occupied with executing another task.

The dual processor model accounts for secondary task interference by stating that the cognitive processer is aiding the motor processer, unless its occupied with other tasks. A recent study tested the notion that the same cognitive processing capacity, that according to the dual processor model is involved in initiating familiar keying sequences and increasing their execution rate (Verwey 2001), is responsible not only for identifying tones, but for counting targets too (Verwey et al. in press).

The present study

In the present study we further examined the cognitive processor. We were interested to see if task integration, the act of putting the secondary task in the motor sequence, occurs with two highly distinguishable tasks. We were also interested to see if the act of identifying and counting a tone in a sequence causes the segmentation of that sequence at those keys. To test this notion the following set-up was established.

Participants took part in a discrete sequence production task with a secondary listening task. During this test the participants practiced two 7-key sequences and in those sequences a fixed tone was presented at either stimulus 3 (S3) or stimulus 5 (S5). They completed 6 blocks, 540 trials per sequence.

The secondary task was to identify and count the number of target tones per block. The target tone was 698 Hz as opposed to the distracter tone of 440 Hz. Participants were familiarized to these tones by repeated listening to them five times before the experiment. Participants in previous similar studies indicated no problems distinguishing between these tones (Verwey et al. in press), thus eliminating the possibility of an non-induced extra strain on the cognitive processor.

Classifying a tone as being low or high pitched is probably an uncommon, non-automated process that requires cognitive processing (Johnston & McCann, 2006). It is therefore only logical to assume the cognitive processor is responsible for this process. A recent study, currently still pending, provided evidence that counting is also performed by the cognitive processor (Verwey et al. in press)

In the testing phase participants performed the same sequences. The test block was split up in three smaller blocks with 45 trials each. The blocks consisted of the same task as the practicing phase, but the secondary listening task three conditions: The tone is present in the same configuration as it was in the practice phase (Control condition), the tone location is swapped between the two sequences (Swap condition) or the tone is not present at all (No Tone condition). The participants still counted the number of target tones per block. The unchanged condition was used as a control condition. The order of these conditions was counterbalanced.

Expectations

If the task of identifying a tone causes a segmentation of the sequence during the practise phase, this can be determined by detecting a higher response time at T3 and T5 in the No Tone condition. The absence of a tone rules out that the expected higher response times at T3 (early sequence) and T5 (late sequence) is caused by the cognitive processor processing and indentifying a tone. This suggests segmentation has occurred, where the motor sequence is divided at the tone location keys during practice.

Another expected effect is a significant performance drop when the tone is presented on the others sequence's location. We expect to see a longer reaction time for T3 in the late sequence and T5 for the early sequence in the Swap condition. In case the performance rates drop significantly this provides arguments that task integration had occurred.

The dual processor model explains the expected decline in performance by assuming that the cognitive processor is no longer speeding up performance by selecting the chunks that the motor processor executes, since it's occupied by the now no longer automated listening task. Under a shared resource model this drop is not expected since the cognitive load remains the same as before.

It is expected that response times will increase in the two conditions that differ from the practice setting. This increase consists of an expected higher response time in the no-tone condition at T3 in the early sequence and at T5 in the late sequence indicating segmentation had occurred. In the swap condition T3 and T5 are expected to be significantly higher, possibly even back to the earlier practicing block level, providing evidence that task integration had occurred.

Method

Participants

24 Right-handed participants took part (age ranging from 18 to 26, M = 20.3) recruited through a credit system of the University of Twente. Participants were rewarded 3 credits (one for every hour) for their effort. The study had been approved by the ethics committee of the Faculty of Behavioural Sciences of the University of Twente.

Procedure

Upon entering the lab, participants received a written instruction of the experiment and signed an informed consent form. Participants were instructed to perform the 7-key sequences as fast as possible with as little error as possible. The participant completed the six practice blocks after additional instruction appeared on the screen. The instruction started off by letting the participants place their fingers on the buttons used and putting on the headphones to ensure the ability to distinguish the tones. They were left alone at this point to avoid distractions. Monitoring occurred through a closed video circuit.

The discrete sequence production- and listening task

The sequencing task involved two 7-key sequences carried out with the middle and index finger of both hands. Participants were presented with four black square placeholders horizontally in the centre of the computer screen against a white background. To mimic the positions of the response keys on the keyboard there were 0.7 cm gaps between the four placeholders. Participants sat with their fingers resting lightly on the c v b and n keys of a regular computer keyboard. Left middle finger on the c key, left index finger on the v key, right middle finger on the n key and the right index finger on the b key.

A stimulus involved filling the placeholders with green after which the participants responded by pressing the spatially compatible key. When the correct key had been pressed, the color in the square changed back to the background color. Errors resulted in the message "wrong key" (in Dutch) for 500 ms after which the correct key had to be pressed any way. In addition, the message "too early" was displayed when participants pressed a key before the presentation of the first stimulus of a new sequence after the pause from the previous sequence.

In one sequence a tone was presented together with the third key-press and in the other sequence a tone was presented with the fifth key press. The sequences will be referred to as early or late sequences from this point onward. The tone was either high (698Hz) or low (440Hz), selected randomly and lasted 100ms. Participants were familiarized to these tones by repeated listening to them five times before the experiment. No difficulty in distinguishing was reported. The participant had to count the number of low tones and remember that number till the pause of a block, after 40 sequences.

Stimuli were presented in two fixed series of seven, thus requiring two fixed sequences of seven key presses (R1-R7). The term trial is used to denote an entire sequence. The two 7-key sequences were always presented in random order. The time between stimulus n and response n is indicated by Tn. This response time equals the interkey interval (IKI; e.g., the response time between S2 and R2 is T2). The two sequences of each participant were selected from a set of four versions and, across participants, each sequence was used as often as early and late sequences in the practice phase.

The four sequences were created by mapping the numbers of the series 1323124 to each of the four keys so that, across participants, each finger occurred as often at a particular sequential position. For example, one participant had VNB+NVBC and NVCVN+CB ("+" indicating the tone in the practice phase), while the next participant had CBV+BCVN and BCNCB+NV. So although the sequences were random, the position of the tone is always with the third key for the early, and the fifth key for the late sequence.

Practice phase

The practice phase involved the first 6 blocks (out of 7), each including 40 early tone and 40 late tone sequences, yielding a total of 240 practice trials for each sequence. During practice the inter-sequence interval amounted to 1500 milliseconds. Each practice block lasted 15-30 minutes and was followed by a 4 minute break. Halfway through each practice block there was a 20 second break. Performance statistics were presented on screen during each pause regarding the completed block/half block. These statistics included percentage of key pressing mistakes and speed in milliseconds. The message "try to keep it below 8%" in Dutch followed the key pressing mistake percentage. After six blocks a short questionnaire was administered that started with the question of the length of each sequence. Then the participants were asked if the location of the tone in each sequence was fixed or that it varied. When the participants stated that the tone position was fixed, they were asked with which stimulus the tone was presented.

The test phase: secondary task conditions

The test phase involved the 7th block, consisting of three smaller blocks, each with another version of the secondary task but always involving the execution of the two familiar sequences (24 trials with each sequence) in a random order while a tone would be presented in two of the three blocks. The order of the three test blocks was counterbalanced across the 24 participants of each inter-sequence interval group by rotating their order across participants. The test phase started off with an introduction on the screen about the three secondary task versions.

In the testing phase, the tone would either be present at the location as practiced (as a control), or present at the position of the other sequence, meaning the tone position switched between the two sequences. The third condition had no tone at all. The tone identifying task remained the same as in the practice blocks.

There was no pause in between the three test phase blocks other than a short instruction for the next block. Performance feedback was provided on screen after each trial/block. This included percentage of errors; speed in ms; the correct number of low tones. After completing the block a second different questionnaire was administered consisting of questions aimed to test awareness and recognition of test conditions. It started by asking whether participants could reproduce the two sequences that they performed. Then they were to select their two sequences out of a set of 16 sequences. Following was the question of how they remembered the sequences: a) by remembering the order of the stimuli, b) by remembering the position of the keys and/or the squares on the screen, c) by tapping the sequence in their mind of on the table, d) in another way.

Apparatus

Stimulus presentation, timing, and data collection were achieved using the E- prime© 2.1 experimental software package on a standard Pentium© IV Windows XP© PC. Stimuli were presented on a 17 inch Philips 107T5 display running at 1024 by 768 pixel resolution in 32 bit colour, and refreshing at 85 Hz. The viewing distance was approximately 70 cm, but this was not strictly controlled. Tones were presented with adjustable over-the-ears headphones.

Results

Practice phase

Reaction Time

Figures 1 and 2 below shows the gradual improvement of reaction times of each key per session per sequence.

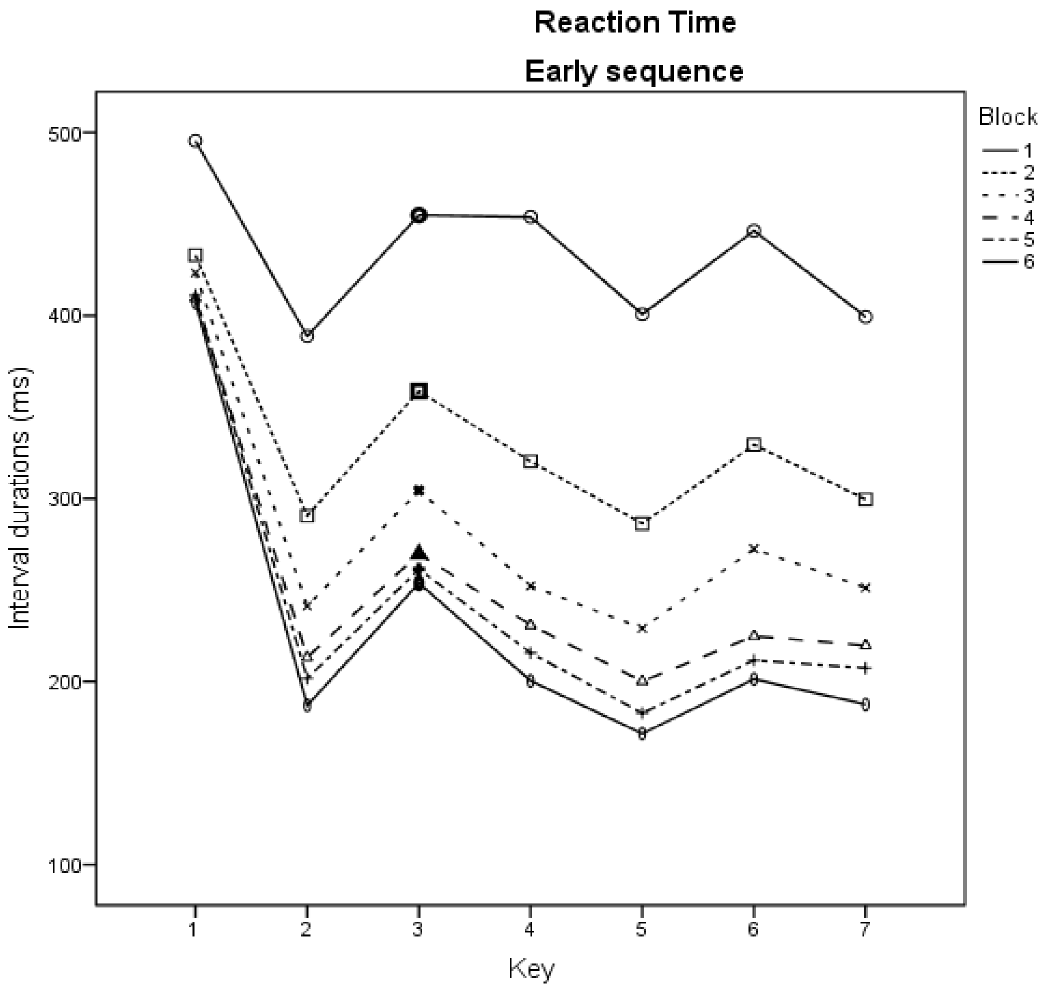

Figure 1: Mean RT's per key across all 6 practice blocks plotted separately for the early sequence. Tone onset was together with onset of S3.

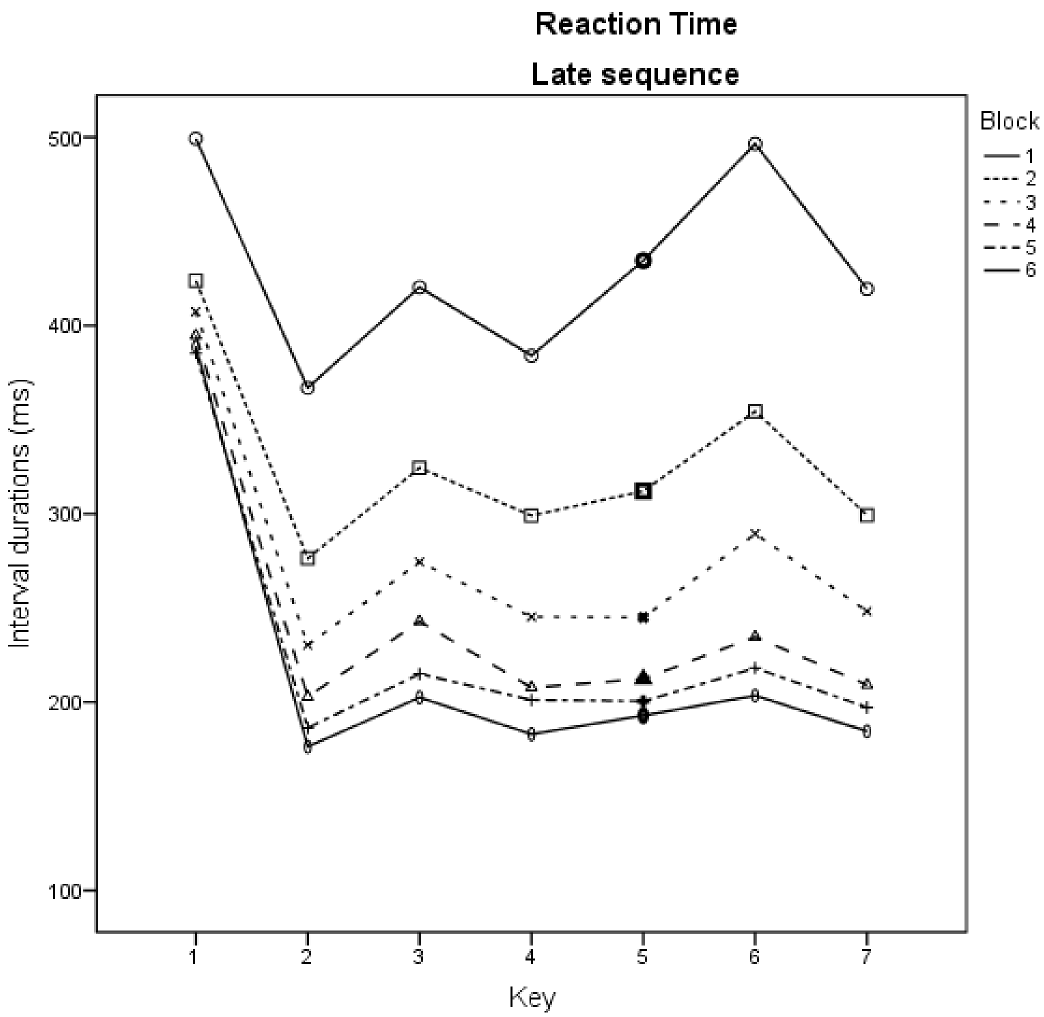

Figure 2: Mean RT's per key across all 6 practice blocks plotted separately for the late sequence. Tone onset was together with onset of S5.

The analysis was performed with a 6 (block) x 2 (tone) x 7 (key) within-subject repeated measures ANOVA on response times (RTs). In addition to block and key main effects, $F(5,36.75)=165.310$, $p < 0.0005$, $\eta p^2 = .878$; $F(6,62.76)=63.931$, $p < 0.005$. It revealed a Block x Key; $F(30,166.06) =15.195$, $p < 0.005$, $\eta p^2 = .398$ and Sequence x Key interaction; $F(6,80.25) =2,787$, $p = .038$, $\eta p^2 = .108$ showing that improvement differed across the different key presses in regards of tone position.

Errors

Sequences that were wrongly executed (e.g. wrong key press) were excluded from further response times analysis. None of the participants had an error rating above 8%. Average error rating per block remained under 3%.

Test phase

Reaction Time

Figure 3 and 4 presenting reaction times for each of the conditions per key, divided per sequence. Note that the early sequence for the Swap condition is the same as the late sequence for the Control condition.

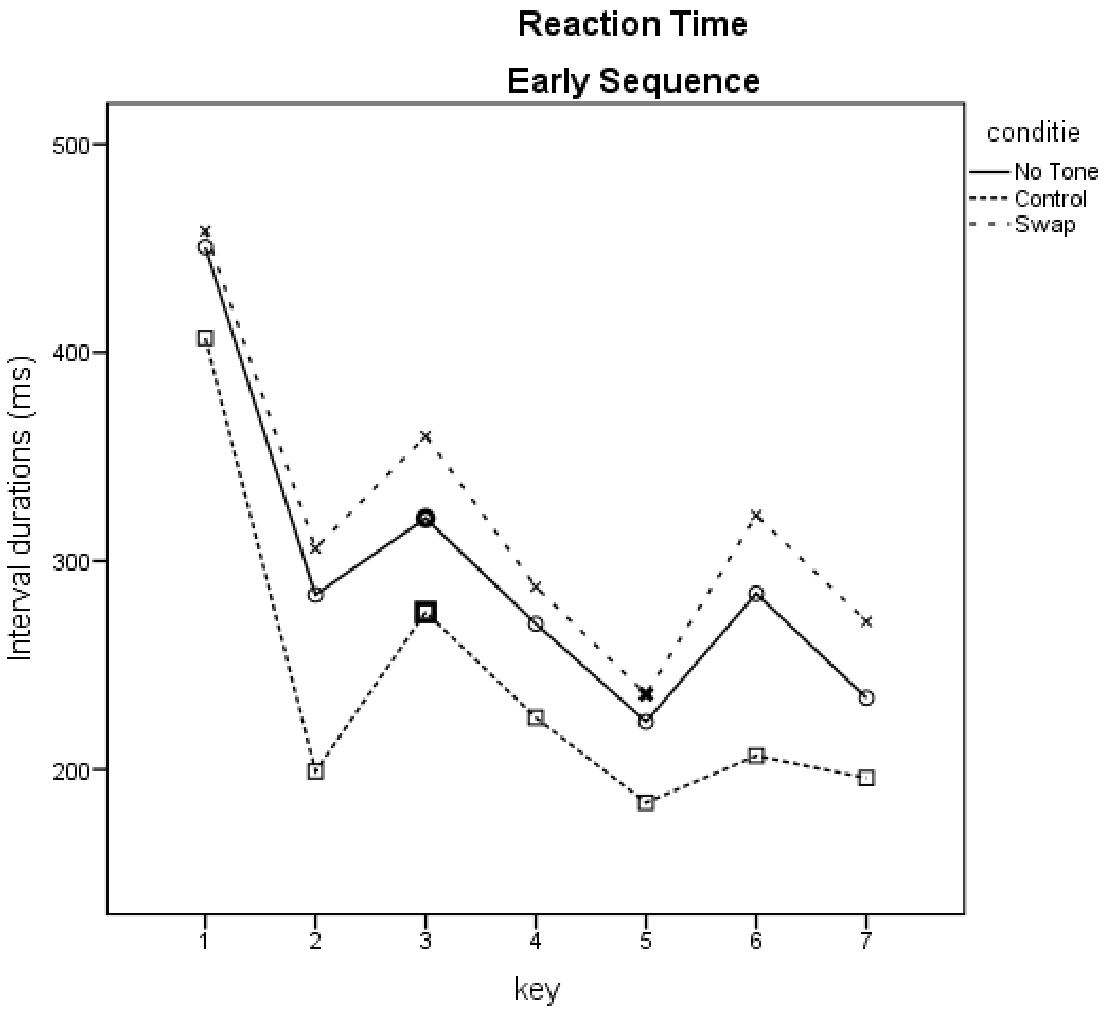

Figure 3: Mean RTs per key across the three conditions plotted separately from the early sequence. In bold the keys that had the tone present in the practice phase.

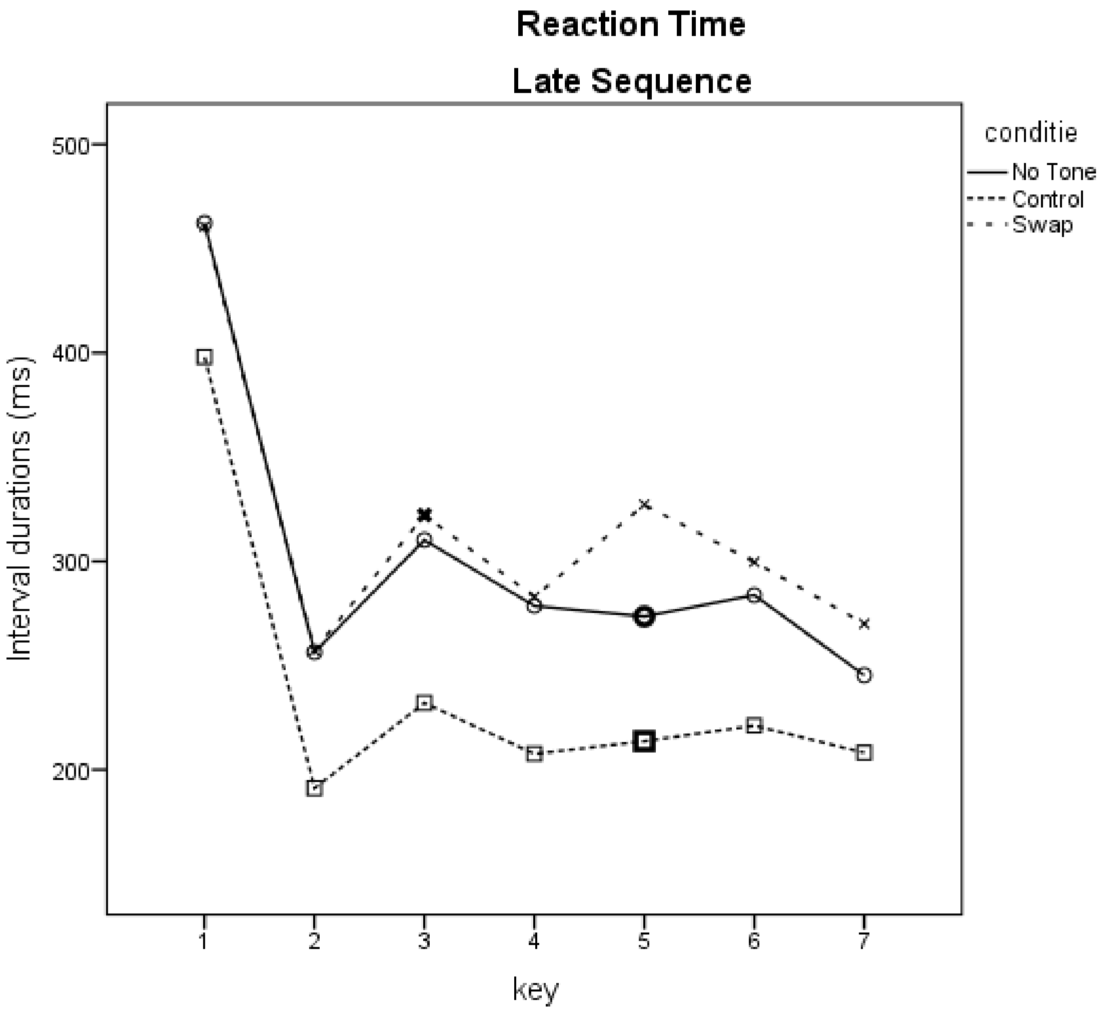

Figure 4: Mean RTs per key across the three conditions plotted separately from the late sequence. In bold the keys that had the tone present in the practice phase.

Reaction times were analyzed using a 3 (Condition) x 2 (Tone position 3 vs. 5) x 7 (Keys) mixed within factors ANOVA on RTs. The ANOVA showed main effects of Condition $F(2,33.469) = 12.501$, $p < .005$, $\eta p^2 = .352$ and Key $F(6,62.98) = 53.88$, $p < .005$, $\eta p^2 = .701$. However an interaction between Sequence and Key $F(6,70.24) = 4.164$, $p = .009$, $\eta p^2 = .153$ was also present as expected.

Pair wise comparison of condition means showed that the Control condition (M = 240.36, SD = 18.34) was significantly different from the No Tone condition (M = 298.30, SD = 27.43) p = .015 and the Swap condition (M = 218.60, SD = 29.28), p = .001, meaning performance was significantly worse for the Swap condition and the No Tone condition when compared to the Control condition.

Our hypothesis was that performance would suffer on T3 and T5 in the altered conditions because that's where the secondary task conditions were formerly present. To test this hypothesis we further analyse these key presses.

In the Swap condition the tone location was switched between the two original sequences. Planned comparison of T3 and T5 from the swap condition with T3 and T5 from the control condition was performed. A paired-samples t-test was conducted to compare the mean reaction time for T3 (Swap/early sequence) ($M=359.86$, $SD=207.27$) to T3 (Control/late sequence) ($M=232.08$, $SD = 131.43$), $t(23) = 3.59$, $p = .002$ (two-tailed) and for T5 (Swap/late sequence) ($M = 327.14$, $SD = 225.74$) to T5 (control/early sequence) ($M = 184.11$, $SD = 89.53$), $t(23) = 3.61$, $p = .001$. T3 as well as T5 in the two conditions were significantly different.

In the No Tone condition the secondary task was removed entirely. We compare T3 (early sequence) and T5 (late sequence) with the T3 (early sequence) and T5 (late sequence) from the Control condition. A paired-samples t-test was conducted to compare the mean reaction time for T3 (No Tone) ($M=320.50$, $SD = 164.85$) to T3 (Control) ($M=275.53$, $SD = 139.61$), $t(23) = 1.98$, $p =.060$ (two-tailed) and T 5(No Tone) (273.50, $SD = 145.89$) to T5 (Control) ($M = 213.71$, $SD = 121.63$), $t(23) = 2.32$, $p = .029$ (two-tailed). T5 was significantly different between conditions.

Errors

In the test phase errors in the sequence execution were: 2.7% for the Control condition; 3.7% for the Swap condition; 3.1% for the No Tone condition. These sequences were removed for the reaction time analysis. A between-groups analysis of variance was conducted to explore the impact of group condition on error levels, as measured by a wrongfully executed sequence. There was a statistically significant difference in error frequencies for the three condition groups: $F(2,24985)=7.2984$, $p= .001$. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for the Control condition ($M = .97$, $SD=.163$) was significantly different from the No Tone condition ($M=.97$, $SD = .173$) and the Swap condition ($M = .96$, $SD = .190$).

Tone Counting

An analysis was performed on the tone counting numbers to check the performance of the participants. The task doesn't seem to be completed well. The number of tones was answered correctly only 27% of the blocks, with a standard deviation of 4.89.

Questionnaires

The questionnaire administered after block 6 contained questions regarding the sequences and the tone. Mean reported sequence length was 10.9 and 11.3 while the actual sequence length was 7. An average of 68.7% stated that the tone location varied. The follow up question asked where the tone was located, and was not shown before answering the varied location question as not to influence this result. As a result only the participants that answered that the tone location was stable answered this question. For the early sequence 37.5% answered correctly, the late sequence scored worse at 12.5%.

The second questionnaire was longer and administered after block 7. The participants were asked to write down the letters representing the keys of the two sequences. Both sequences were correctly recalled only 29.2% of the times. Then the participant was given a table with 16 possible sequences and asked to pick out the ones they performed. This table was not accessible when they had to write down the sequences. The first sequence was recognized correctly 58.3% vs. 54.2% for the second sequence.

Only 8.3% of participants stated they remembered the sequences because they remembered the letter orders; 41.7% remembered the position of the keys or the squares on the screen; 45.8% remembered by tapping their fingers on the table or visualized tapping in their mind.

Discussion

Task integration

We were interested to see if task integration occurs with clearly different tasks. The current results confirm that even during automated sequence production underlying processes are still active: Sequence performance was slowed down considerably when the secondary task conditions changed. The finding that sequence performance suffered in the Swap condition favours the dual processor model above a resource based model, since the cognitive load remains equal among these conditions. The dual processor model can explain the decline in performance by assuming the secondary task had been integrated in the sequence. Changing the location of the tone in the automated sequence results in an entirely new non-automated sequence. The cognitive processer is no longer speeding up the sequence execution by selecting motor chunks, since it is now occupied with non automatic sequence production. The performance is significantly worse at the new tone positions T3 and T5 because presumably the cognitive processer has three jobs at this point: It must recognize and count the target tone, whilst also selecting the next key in the sequence. The processing is not flexible enough to alter secondary task location in the sequence, thus under the new condition the sequence has to be re-automated. These present results support the hypothesis that task integration can occur between two different tasks.

Segmentation

The other condition involved no tone in the two sequences at all and performance significantly suffered here as well. Given that the cognitive load is actually less than in the Control condition, these results are not congruent with a resource based model. More processing power should be available to enhance the sequence execution, thus enhancing performance. Our results however showed a significant decline in overall performance. The dual processor model can explain the decline in overall performance in regards to the original condition by stating task integration had occurred and now the secondary task is no longer present, the task is considered new.

Another expectation was the significant difference between condition No Tone and Control of T3 and T5. The difference of T3's was not significant, but this could be the result of the relatively low sample size. Assuming that the difference of both T3 and T5 would be significant with a higher sample size it proves that the slowing of T3 and T5 in the Swap condition is not caused by the load of the secondary task, or at least not entirely.

The goal of this study was to explore sequence task results with the dual processor model to see if task integration occurs with two clearly different tasks. The results from the Swap condition indicate that task integration had occurred during practice because of the higher response times at T3 and T5. This integration occurs regardless of the subjects awareness of the location of the secondary task. The results from the No Tone condition provide further evidence that these higher response times are the result of task integration and not of a higher cognitive load because the higher response times were still present when there was no such load.

Errors in tone counting

The number of errors made in the tone counting task are quite high and thus indicate that participants either did not take this task seriously or it was too hard. If participants did not take this task seriously it could mean the cognitive processor was not being loaded as much as it was intended. However the rate of error can be at least partly explained by examining the structure of the program used for the measuring. When an error in a sequence was made, the sequence was paused shortly and the erroneous key had to be repeated. This could include the tone if this erroneous key was the tone location key. Instructions regarding tone counting specified to count all the target tones, no mention was made of the tones that were repeated. Closer examination of the tone counting data reveals that 43% of the answers over-stated the number of tones versus 31% that under-stated it. 63.3% Of all the answers was within two errors from the correct answer, which is an acceptable score.

Implications

The implications of these findings can be found in numerous fields of industry. When updating protocols one can expect a significant worse performance and more than normal errors for a grace period, even if the updated protocol is just slightly different from the previous version. Even when removing items from a movement sequence the new shorter sequence might take longer than before! This applies to virtually all fields in which sequence production has become an automated process, like assembling products on the line that has always been done in a particular order or perhaps even surgery. Of course each subject should be addressed and evaluated individually for the occurrence and significance of these performance problems.

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