Task integration in the DSP task

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Abstract

In the present study we wanted to examine whether there will be a race between the motor processor and the cognitive processor from the Dual Processor Model (DPM). By adding a secondary tone counting task to the primary Discrete Sequence Production (DSP) task and using other hand configuration. Our main prediction was that reaction times will be slower when participants counted the target tones while executing the sequences with other hand configuration. Twenty four students from the University of Twente and Saxion Hogescholen participated in an experiment with a practice and a test phase. In the practice phase participants executed the sequences with two hands and on the third key position a tone was presented. In the test phase the participants used in two of the four sub blocks two hands and in the rest of the sub blocks they used the left hand. The tones were presented on the third and the fifth key position in the test phase. Twelve of the 24 participants were the control group where they ignored the presented tones in both the practice and the test phase. Only the reaction times data was analyzed, with (within subject) repeated measures ANOVA. Results supported our main prediction that counting target tones while using unpracticed hand configuration will slow the reaction times. .

1. Introduction

Driving a car or playing an instrument are a few activities in daily life that require motor skills. There are two experimental paradigms to understand how these motor skills are acquired and controlled (Doyon, Penhune & Ungerleider, 2003). The present study uses tasks based on the motor sequence learning paradigm to understand the acquisition of motor skills.

Motor sequence learning means acquiring the skill to produce a sequence of movements as accurately and rapidly without any effort (Abrahamse, Ruitenberg, De Kleine & Verwey, 2013). Most of our everyday life activities require motor skills that use sequential structure, therefore it has been an important topic in research in the last decades. This research lead to the development of many sequence acquisition tasks (Abrahamse et al., 2013).

One of the tasks that are used to investigate sequence learning is the Discrete Sequence Production (DSP) task. In the DSP task participants have to place four to eight fingers on the designated keys of the computer keyboard. On the computer screen are displayed the same number of small square placeholders, each placeholder corresponds to one of the keys on the computer keyboard in a spatially compatible way. When a placeholder lights up, the participant has to press rapidly the compatible key on the computer keyboard. After reacting to the stimulus, the next stimulus is displayed on the computer screen. A sequence in the DSP tasks has two fixed series of 3-7 stimuli. There are two phases in the DSP task, the practice phase and the test phase. In the practice phase, participants practice each sequence 500-1000 times. By practicing, participants develop motor chunks, which are responses that can be selected and executed as if they are one response (Abrahamse et al., 2013). In the test phase participants execute unfamiliar sequences, that serve as the control condition.

One of the cognitive models that account for the capacity to acquire sequential skill, is the Dual Processor Model (DPM). DPM includes two processors, the cognitive processor and the motor processor. The sequence execution has three modes, the reaction mode, associative mode and the chunking mode (Verwey & Abrahamse, 2012). When practicing a keying task, participants use each stimulus, specific to the key, to react, this is the reaction mode. An associative mode involves when the responses are primed by previous response, but still need stimulus processing. In the chunking mode participants only use the first key-specific stimulus, the so called motor chunk, to response to the discrete sequence. After practising, a mental representation of the sequences or parts of longer sequences can develop, this representation is called motor chunk. The cognitive processor loads these motor chunks into the motor buffer. The motor processor can use these chunks as a single stimulus, after being triggered by the cognitive processor to read the codes for each movement and execute the series of movements relatively autonomous (Abrahamse et al., 2013). studies showed that longer sequences are executed as more than one successive segment (Abrahamse et al., 2013). The process of these rapid successive segmentation is called concatenation, where different chunks within a sequence are executed as smoothly as possible. When a sequence contains more than one chunk, only the first key-specific stimulus of each chunk needs preparation. The point where the first key-specific stimulus of the next chunk within a sequence is initiated, is called the concatenation point. At the concatenation point, the reaction times can be slower, due to preparation for the motor chunk. When the circumstances are right, the motor processor and the cognitive processor will race each other. In the race the motor processor will trigger a response from the motor buffer and the cognitive processor select each key-specific response (Verwey, 2001). The cognitive processor may also use explicit sequence knowledge or spatial/verbal coding in the race with the motor processor. During the execution of the DSP task participants can obtain explicit knowledge about the sequences. The explicit knowledge about the structure of the sequences can be verbal knowledge as well as spatial knowledge (Abrahamse et al., 2013). Spatial knowledge means the knowledge about the spatial position of the different elements of the sequence. Verbal knowledge refers to being able to verbally reproduce the different elements of the sequences.

A way to examine the race between the motor processor and the cognitive processor is to add a secondary task to the primary DSP task. Verwey et al. (2010) showed that adding a tone counting task to the DSP task as a second task, the response times after tone presentation were slower. By adding a tone task, the cognitive processor shifts from the race with motor processor to counting the target tones. The motor processor then does not have to race, which will make the motor processor respond a little slower and continue in the chunking mode. Another way of examining the race between the motor processor and the cognitive processor is to add an alteration to the DSP Task, such as changing hand configuration. A study by Verwey and Wright (2004) showed that participants performed practiced sequences faster with the hand configuration they had used during practice, and slower with a new hand configuration. Using other hand configuration in the test phase requires a lot more cognitive involvement. According to these earlier studies, adding a secondary task or an alteration, the cognitive processor will either shift from the race in the primary task to another task or it will get involved more in the execution of the sequences. It is therefore interesting to investigat whether there will be a race between the cognitive processor and the motor processor when both a secondary task and an alternation is added to the primary DSP task. This allowed us to hypothesize that using other hand configuration there will be a shift from the chunking mode (motor) and counting target tones there will be a shift from the associative mode (verbal/spatial).

Based on earlier studies our first prediction is that counting target tones in the secondary task will slow the reaction times on the keying sequences. Our second prediction is that using other hand configuration in the test phase of the primary DSP task, the reaction times on the keying sequences will be slower. In the present study the alteration is using one hand in two of the sub blocks in the test phase, instead of using the two-handed configuration of the practice phase. Our third prediction is that reaction times on the keying sequences will be slower when participants count target tones while executing the keying sequences with other hand configuration. To find any effects of the secondary task and the alteration on the performance of the keying sequences, an experiment with a practice and a test phase was set up.

2. Methods

Participants

Twenty four students from the University of Twente and Saxion Hogescholen participated in the experiment. The participants were between the age of 17 and 32. Eligibility requirements for the participants were that they were not older than 35 years, they were not smokers, they had no motor and visual impairments and they were not allowed to consume alcohol in the 24 hours prior to the experiment. Participants from the University og Twente had to assign for the experiment via SONA-Systems of the university of Twente and obtained 3 credit points per participant. Participants from the Saxion Hogescholen had to assign by email. There was also a lottery where participants could win 50 Euro’s.

Materials

For the experiment an E-Prime 2.0 was used for the presentation of stimuli and registration of the data. The program ran on a Pentium computer with Windows XP. A standard QWERTY-keyboard and a Sennheiser headphone was used.

Tasks

DSP task

The DSP task consisted of two phases. The practice phase consisted of 6 blocks, with 120 7-key sequences per block, with four minutes break between each block. An additional task was added to the DSP task: counting low tones. During the whole experiment, participants heard high and low tones through a headphone. Twelve participants, the experimental group, were instructed to count the low tones during the DSP task execution and twelve participants, the control group, were instructed to ignore the tones, but had keep the headphone on. Participants had to place their left middle finger on the C key of the keyboard, the left index finger on the V key and their right index finger on the B key and their right middle finger on the N key. On the computer screen four square placeholders would appear, each time a square would lit up, the participant had to press the corresponding (compatible) key on the keyboard. At the same time they would hear high and low tones and had to count the low ones. In the practice phase the tones were presented in the third position. If a participant pressed the wrong key, on the screen would appear they had pressed the wrong key.

The test phase consisted of 1 block with four sub blocks, each with 48 sequences. In two blocks participants had to use both hands, just as in the practice phase and in two blocks participants had to use only their left hand. The tones were presented in two blocks on the third position, in one block they were using both hands and in one block they were using just the left hand. The tones were also presented on the fifth position in the other two blocks where participants had to use both hands in a block and the left hand in the other block. Keys in the sequences were counterbalanced for the fingers used in the task.

Awareness Test

After completing the DSP task, participants were asked to fill in the Awareness Test on the computer. The researcher hid all keys on the keyboard, except for the Space key. Participants were asked to click with the left mouse button the horizontally presented square placeholders in the order of the sequences that were presented in the DSP task. They were also instructed to click the right order on the square placeholders with the letters C, V, B, N, but this time these placeholders were presented across the computer screen. After the part where they had to answer the right order, participants had to answer a few questions about how they remembered the order of the sequences.

Paper questionnaire

After filling in the Awareness Test, participants filled in a paper questionnaire consisting of three pages. The paper questionnaire was used to examine the explicit sequential knowledge of participants. Each page had to be filled in, before going on with the next page, Participants were not allowed to go back to a previous page.

Procedure

Participants could assign for the experiment via SONA Systems of the University of Twente, where they also could read more about the experiment. A number of participants did not assign for the experiment via SONA Systems, but via e-mail. These were students from Saxion Hogescholen. The experiment took place in a room at the University of Twente. At the beginning of the experiment the participant was given information about the procedure of the experiment. The researcher also made sure that the participant met the criteria, for example participants were not allowed to consume alcohol 24 hours prior to the experiment. The participant was then asked to fill in the informed consent form. After filling in the informed consent form, the participant had to sit behind the computer and put on the headphone. The researcher started the computer in lean mode, so that and also started the program for the practice phase of the DSP task. On the screen instructions were presented to the participant. The practice phase consisted of 6 blocks. After finishing each block, the researcher started the program again and each time fill in the number corresponding to the participant and the number of the block. The test phase consisted of one block, block seven and included four sub blocks. The participant had to put on the headphone during the whole experiment, even when they were from the control group where they had to ignore the tones. The experimenter made sure that in the test phase the participant met the criteria for each of the test conditions, for example using only the left hand when the participant was instructed to use only the left hand. After finishing the DSP task, participants filled in the Awareness Test on the computer, where the experimenter had to stand next to the participant, to hide all the keys on the keyboard, except for the Space key. At the end of the experiment the participant filled in a paper questionnaire, where they had to answer questions about the sequences. After giving some additional information about the experiment to the participant, the experiment was finished. During the experiment the experimenter also kept a logbook, where the experimenter noted events or anything that could influence the results of the experiment.

Data analyses

For the results a repeated measures ANOVA was conducted for both the data from the practice and the test phase. This means that the control group consisting of twelve participants was left out as well as the data collected from the Awareness Test and the paper and pencil questionnaire of all the 24 participants.

3. Results

Practice phase

To examine the reaction times in the practice phase, a 6 (Block: 1-6) x 2 (Tone High/Low) x 7 (Key) repeated measures ANOVA was conducted on the data. The analysis showed significant main effect for Block $F_{(5, 55)} = 82.91$, $p < .000$. The reaction time decreased with each consecutive block. Participants executed the sequences faster with practice. Practicing the sequences allowed the participants to develop motor chunks.

The analysis also showed significant main effect for Key $F_{(6, 66)} = 15.67$, $p < .000$. The reaction time decreases from first to second key the most, then increase up to key four and then decreases again. The interactions Block x Key and Block x Tone x Key were also significant. For Block x Key interaction $F_{(30, 330)} = 3.41$, $p < .000$, the reaction time decreases with each consecutive key, but decreases more for higher keys. For Block x Tone x Key interaction $F_{(30, 330)} = 2.41$, $p = .000$, the reaction time decreases for each consecutive key within each block and between each block, while this development is more pronounced for the high tone than for low tone. There was no significant main effect found for Tone.

A 6 (Block: 1-6) x 2 (Tone High/Low) x 7 (Key) repeated measures ANOVA was also conducted on the arcsine transformed error data. There were no significant effects found for the error data in the practice phase. The interaction Block x Key is almost significant, $F_{(30, 330)} = 1.47$, $p = .056$. There were no main effects found for Block $F_{(5, 55)} = 1.21$, $p = .316$, for Tone $F_{(1, 11)} = 0.90$, $p = .363$ and for Key $F_{(6, 66)} = 1.54$, $p = .181$.

Test phase

For the test phase a 2 (TonePosition 3 or 5) x 2 (Hand: 1 or 2 hands) x 2 (High vs Low tone) x 7 (Key) repeated measures ANOVA was conducted on the data. The analysis showed significant main effect for Hand , $F_{(1, 11)} = 16.26$, $p = .002$. The reaction time is lower for two-handed than for one-handed trials. This main effect supports the prediction that using other hand configuration, than the one used in practice phase, slows the reaction times. Also for Key there was a significant main effect $F_{(6, 66)} = 7.18$, $p = .000$. The reaction time decreases from first to third key, then increases from third to fifth key and then decreases to the last key. The interaction Hand x Key was determined to be a statistically significant predictor of reaction time, $F_{(6, 66)} = 4.69$, $p = .005$. The analysis shows that the reaction time decreases from first to third key, then increase up to key five and then decreases again to key six. Then the one-handed trials increase in reaction time, while the two-handed trials decrease in reaction time. There were no main effects found for TonePosition $F_{(1, 11)} = 2.42$, $p = .148$ and for Tone $F_{(1, 11)} = 0.85$, $p = .375$.

A 2 (TonePosition 3 or 5) x 2 (Hand: 1 or 2 hands) x 2 (High vs Low tone) x 3 (Key) repeated measures ANOVA was calculated for the data on the six keys after presenting the tones. These keys are T3, T4, T5 for the tone presented on position 3. For the tone presented on position 5, these keys are T5, T6 and T7. Hands as a main effect was determined to be a significant predictor of reaction time, $F_{(1, 11)} = 17.70$, $p = .001$. The reaction time is lower for two-handed than for left-handed trials. The interaction Hand x Tone was determined to be a significant predictor of reaction time, $F_{(6, 66)} = 6.45$, $p = .028$. The reaction time increased from high to low tone with one-handed configuration, while from high to low tone no substantial increase is evident for two-handed configuration (Figure 1). This supports the prediction that using a different hand configuration than the one used in the practice phase while counting tones will slow the reaction times.

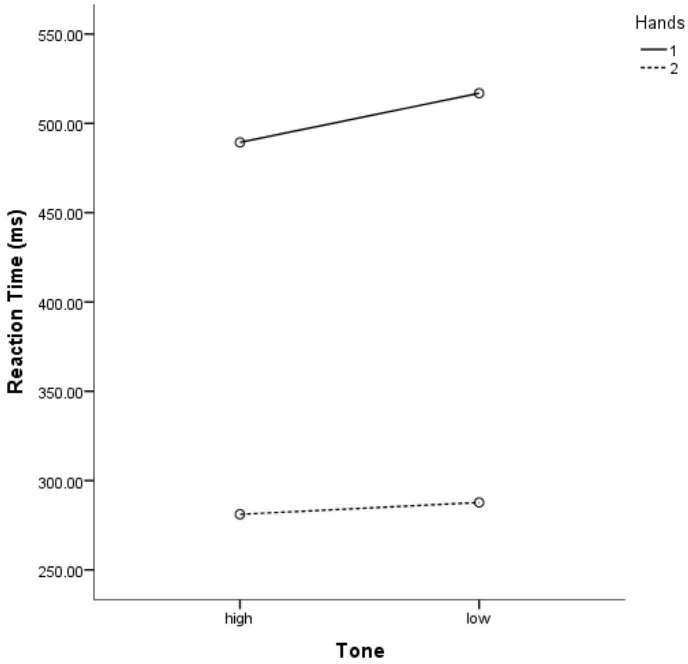

Figure 1. Reaction Time (ms) over the Hand and Tone interaction for the three keys after tone presentation on position 3 and position 5 in the test phase of the DSP Task.

There were no main effects found for TonePosition $F_{(1, 11)} = 0.37$, p = .554, for Tone $F_{(1, 11)} = 2.95$, p = .114 and for Key $F_{(2, 22)} = 0.23$, p = .799.

A 2 (TonePosition 3 of 5) x 2 (Hand: 1 or 2 hands) x 2 (High vs Low tone) x 7 (key) repeated measures ANOVA was conducted on the arcsine transformed error data. Key as a main effect was determined to be a statistically significant predictor of reaction time, $F_{(6, 66)} = 2.32$, p = .043. The reaction time is lower for two-handed than for one-handed trials. There were no significant main effects found for TonePosition $F_{(1, 11)} = 0.54$, p = .478 and for Tone $F_{(1, 11)} = 0.07$, p = .796. The main effect for Hands was almost significant $F_{(1, 11)} = 4.56$, p = .056.

4. Discussion

To answer the question whether there will be a race between the cognitive processor and the motor processor, we tested our hypothesis by testing three predictions. The results support the hypothesis that using other hand configuration there will be a shift from the chunking mode (motor) to the reaction mode and counting target tones there will be a shift from the associative mode (verbal/spatial).

The results from the practice phase show that participants develop motor chunks after practice. The reaction times decreased with each block. The main effect for block confirms the notion from the DPM that with practice there should be a shift from reaction mode to chunking mode. There was no significant main effect found for Tone, yet there was a significant interaction Block x Tone x Key. The reaction times decreased for each key within and between each block, but the reaction time increased for key four and then decreased for key five, six and seven. After tone presentation on key three, the cognitive processor was needed more for the counting task and therefor it is possible that the reaction time on key four was slowed because the motor processor did not race with the cognitive processor.

The results from the test phase support two out of three of our predictions. Our second prediction that using other hand configuration, than the one used in the practice phase, will slow the reaction times. The reaction times for the practiced two-handed configuration was lower than for the one-handed configuration. Through practice effector specific knowledge develops, this means that with practice effector-dependent components will develop. This makes the reaction times slower, when in the test phase the specific knowledge has to transfer to other effector (De Kleine & Verwey, 2009; Park & Shea, 2003; Verwey, 2004). Taking the lack of specific knowledge about the other effector in account, the execution of the sequences got more dependent on the cognitive processor, this can explain the slow reaction times for Hand.

The third prediction that reaction times on the keying sequences will be slower when participants count target tones while executing the keying sequences with other hand configuration, is also supported by the results. For this prediction we zoomed in on the data for the three keys after tone presentation. The keys T3, T4 and T5 for the tone presentation on key three. The keys T5, T6 and T7 for the tone presentation in key five. The interaction Hand x Tone shows that with the one-handed configuration the reaction times increased from high tone to low tone. There is no substantial increase (very minimal) in the reaction time with two-handed configuration. Even though there was no significant main effect found for Tone, the significant Hand x Tone interaction shows that when participants used other hand configuration, while counting target tones, the reaction times slowed. The difference in reaction time for two-handed and one-handed configuration is more than 200 ms for Hand as a main effect over all the keys. After tone presentation, at both tone positions, this difference is larger than the previous difference. The larger difference supports our third prediction even more. That both adding a secondary task and using other hand configuration will slow the reaction times a lot more, than with just a secondary task or with just an alteration (using other hand configuration).

The overall described results from the test phase do not support our first prediction that counting target tones in the secondary task, will slow the reaction times on the keying sequences. There was no significant main effect found for Tone, both in the overall test phase results as well as in the results from the three keys after tone presentation. An explanation for the lack of significant effects might be that during the practice phase participants learned knowledge about the tones and tone position. The learned knowledge would then not need much effort from the cognitive processor. This gives the cognitive processor more room to race with the motor processor where the motor processor wins the race. Race between the cognitive processor and motor processor can make the motor processor respond faster than when the motor processor is not in race (Abrahamse et al., 2013).

Nevertheless the results support our hypothesis because even when there is no significant main effect found for tone, the interaction Hand x Tone is significant after tone presentation.

The data from the Awareness Test and the paper questionnaire as well as the control group were left out from the analysis, the main focus was on the reaction times of the experimental group. For further studies it might give a better picture of the effect of tone one the reaction time, by comparing the two groups. The results might contain significant differences in reaction times of participants that counted the tones and participants that ignored the tones. The data from the Awareness Test can give more information about the explicit sequence knowledge of participants. Using explicit sequence knowledge can increase the execution rate of sequences (Verwey, 2015). Examining the data from the Awareness Test can provide an insight in whether participants developed and used explicit sequence knowledge during task execution. The data from the paper questionnaire can also provide an insight in the explicit sequence knowledge of the participants or the lack of it.

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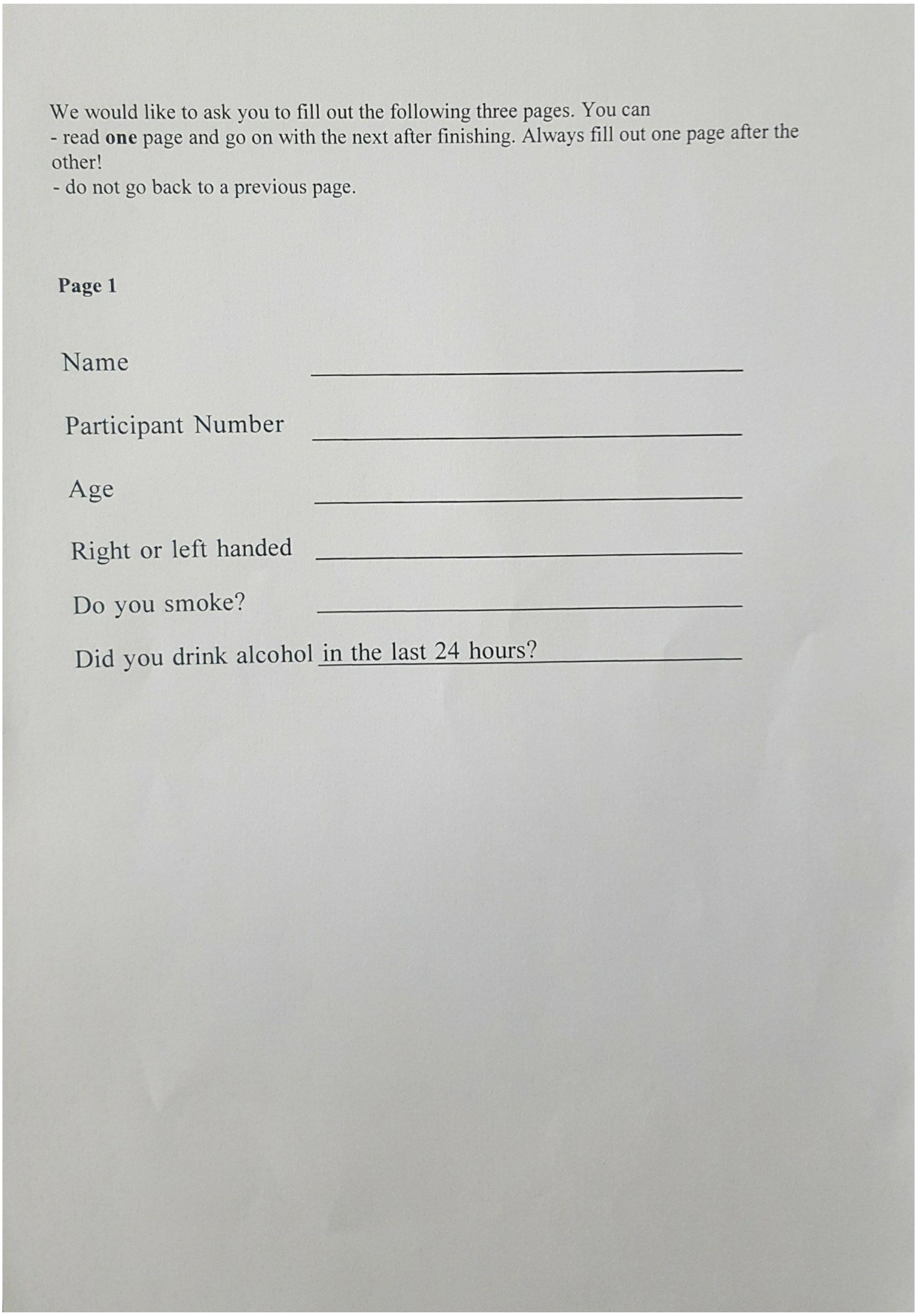
Appendices

Paper questionnaire Paper questionnaire used in the experiment, but the data was left out in the analysis and results.



We would like to ask you to fill out the following three pages. You can
- read **one** page and go on with the next after finishing. Always fill out one page after the other!
- do not go back to a previous page.

Page 1

Name ______________________

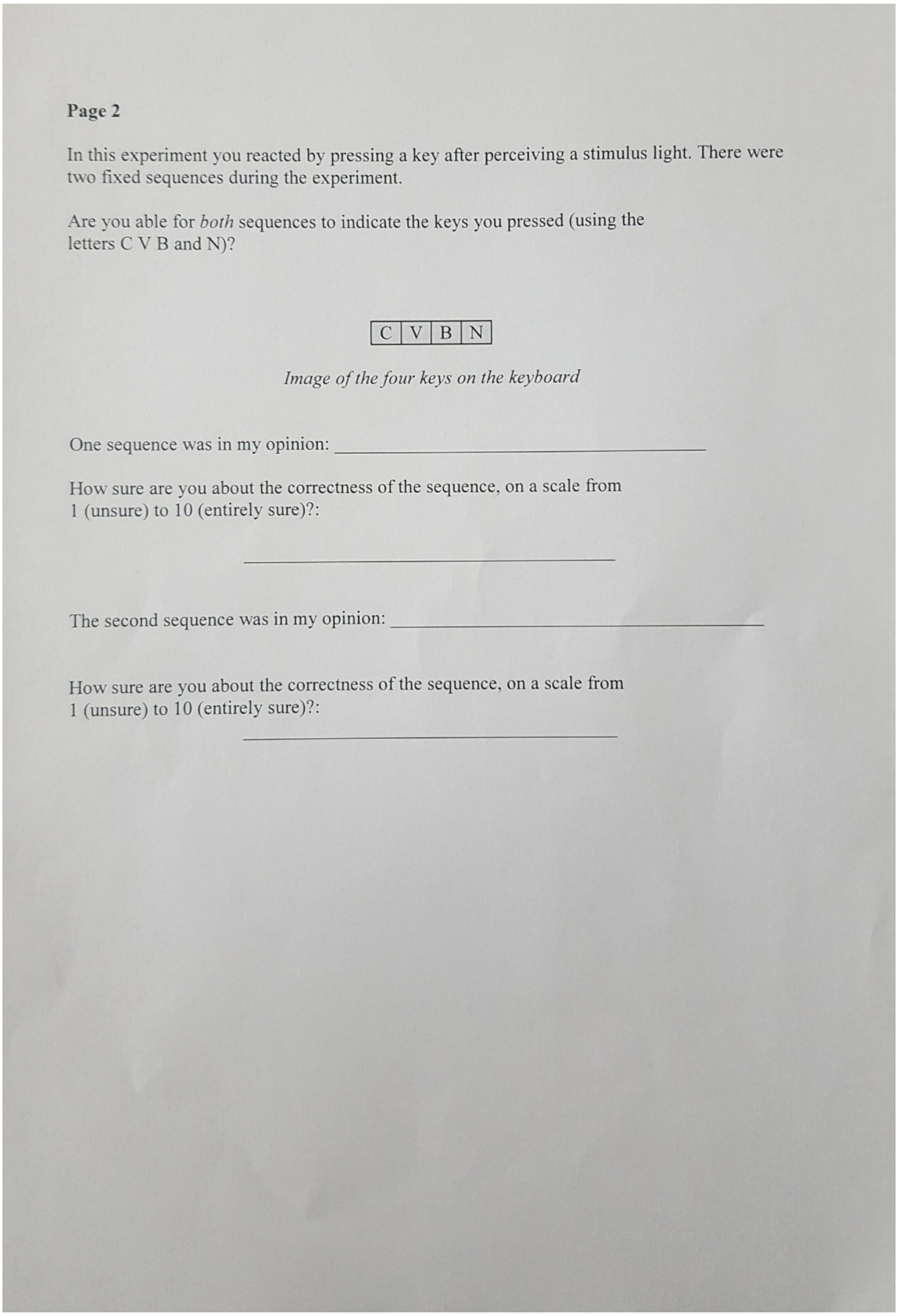
Participant Number ______________________

Age ______________________

Right or left handed ______________________

Do you smoke? ______________________

Did you drink alcohol in the last 24 hours? ______________________



Page 2

In this experiment you reacted by pressing a key after perceiving a stimulus light. There were two fixed sequences during the experiment.

Are you able for *both* sequences to indicate the keys you pressed (using the letters C V B and N)?

C	V	B	N

Image of the four keys on the keyboard

One sequence was in my opinion: ____

How sure are you about the correctness of the sequence, on a scale from 1 (unsure) to 10 (entirely sure)?:

____

The second sequence was in my opinion: ____

How sure are you about the correctness of the sequence, on a scale from 1 (unsure) to 10 (entirely sure)?:

____

Page 3

1) How were you able to recognize the sequences at the previous pages of this survey? (you may circle more than 1 alternative).

a) I remembered the order of the letters.
b) I remembered the positions of the keys
c) I remembered the positions of the squares on the screen.
d) I tapped the sequence in my mind
e) I tapped the sequence on the table top.
f) Differently, namely:

2) How did you count the tones? (you may circle more than 1 alternative)

a) I repeated the *pitch* of the low tones in my head all the time
b) I repeated the number of earlier counted tones in my head while executing sequences
c) I repeated the number of earlier counted tones in my head only after completing a sequence
d) I increased the number of tones during sequence execution
e) I increased the number of tones after I completed a sequence

3) Have you participated before in an experiment with keying sequences?
If yes, did it contain the same sequences?

4) Do you have any remarks about the experiment?

Main and interaction effects on reaction times in the test phase.

Table 1.

Repeated Measures ANOVA to explain reaction time by TonePosition, Hand, Tone, Key and their interactions.

	F	df1, df2	p	$\eta^2_{partial}$
TonePosition	2.42	1, 11	.148	.181
Hand	16.26	1, 11	.002	.596
Tone	0.85	1, 11	.375	.072
Key	7.18	1, 11	.001	.395
Position * Hand	0.28	1, 11	.608	.025
TonePosition * Tone	0.43	1, 11	.527	.037
Hand * Tone	2.89	1, 11	.117	.208
TonePosition * Hand * Tone	0.66	1, 11	.433	.057
TonePosition * Key	2.07	1, 11	.144	.158
Hand * Key	4.69	1, 11	.007	.299
TonePosition * Hand * Key	1.09	1, 11	.371	.090
Tone * Key	2.22	1, 11	.097	.168
TonePosition * Tone * Key	1.43	1, 11	.252	.115
Hand * Tone * Key	1.27	1, 11	.301	.104
TonePositie * Hand * Tone * Key	0.14	1, 11	.904	.013

Table 2.

Repeated Measures ANOVA to explain reaction time on the keys T3, T4, T5 and on the keys T5, T6, T7 by tone TonePosition, Hand, Tone, Key and their interactions.

	F	dfs	p	$\eta^2_{partial}$
TonePosition	0.37	1, 11	.554	.033
Hand	17.70	1, 11	.001	.617
Tone	2.95	1, 11	.114	.211
Key	0.23	2, 22	.799	.032
TonePosition * Hand	2.46	1, 11	.145	.183
TonePosition * Tone	0.75	1, 11	.405	.064
Hand* Tone	6.45	1, 11	.028	.370
TonePosition * Hand * Tone	0.52	1, 11	.484	.045
TonePosition * Key	3.08	2, 22	.066	.419
Hand * Key	1.11	2, 22	.348	.182
TonePosition * Hand * Key	0.16	2, 22	.853	.066
Tone * Key	0.75	2, 22	.485	.157

TonePosition * Tone * Key	0.53	2, 22	.597	.078
Hand * Tone * Key	0.29	2, 22	.750	.072
TonePosition * Hand * Tone * Key	0.71	2, 22	.504	.410

Table 3.

Repeated Measures ANOVA on arcsine transformed error data to explain error proportion by TonePosition, Hand, Tone, Key and their interactions.

	F	dfs	p	$\eta^2_{partial}$
TonePosition	0.54	1, 11	.478	.047
Hand	4.56	1, 11	.056	.293
Tone	0.07	1, 11	.796	.006
Key	2.32	6, 66	.043	.174
TonePosition * Hand	1.40	1, 11	.262	.113
TonePosition * Tone	0.64	1, 11	.439	.055
Hand * Tone	0.18	1, 11	.680	.016
TonePosition * Hand * Tone	0.07	1, 11	.792	.007
TonePosition * Key	0.57	6, 66	.750	.050
Hand * Key	2.00	6, 66	.077	.154
TonePosition * Hand * Key	0.39	6, 66	.883	.034
Tone * Key	0.83	6, 66	.555	.070
TonePosition * Tone * Key	1.19	6, 66	.325	.097
Hand * Tone * Key	0.49	6, 66	.814	.043
TonePosition * Hand * Tone * Key	1.52	6, 66	.187	.121