Understanding the Basis of Mindfulness-Based Enhancement for Motor Learning

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Abstract

Previous research has highlighted the role of cognitive control in goal directed activities, like motor sequence learning (MSL). Moreover, these studies address the modulation of cognitive functions through cognitive enhancement activities, like single-session meditation. Although a single session of *focused attention meditation* (FAM) biases practitioners towards employing an external stimulus-based strategy, we are curious if other meditation techniques like *open monitoring meditation* (OMM) induce different effects. Participants performed a cognitive training with either a single session of FAM (n = 16), OMM (n =16) or listening to a podcast (n = 16) in the control condition before engaging in six training and two testing blocks of the dance-step version of the Discrete Sequence Production (DSP) task. Moreover, since effort plays a crucial role in goal-directed activities, it was assessed with a questionnaire at (1) baseline, (2) after cognitive training, (3) after three training blocks and (4) after finishing the six training blocks of the DSP task. After OMM, participants started with longer response times (RT), continued to make mistakes, had more concatenation, had longer RT on unfamiliar sequences and greater RT improvement during training compared to FAM and the control condition. Hence, FAM and OMM revealed distinct effects on cognitive control in line with previous research. It was found that FAM evokes a persistence metacontrol state thereby inducing an external stimulus-based strategy during MSL, while it was suggested that OMM biased participants towards a flexibility metacontrol state thereby eliciting an internal plan-based approach to MSL. Opposed to previous work, our results revealed a positive correlation between effort during cognitive training and MSL improvements. Despite similar performance of OMM and FAM groups at the end of training, the findings imply that cognitive control has a crucial influence on how MSL is approached.

1. Introduction

1.1 Understanding the Basis of Mindfulness-Based Enhancement for Motor Learning

Motor sequence learning (MSL) is an important aspect of our daily lives, for instance when driving, cooking or typing on a keyboard. Many of these motor actions evolve into routine behaviours without much conscious effort needed for their performance. Usually, they require deliberate attention towards goal selection, action selection and action execution (Krakauer et al., 2019). Although the exact learning mechanisms and underlying cognitive processes are still being delineated by cognitive science, cognitive control plays a crucial role in these different motor learning steps (Chan et al., 2018b). Cognitive control is characterised by "the intentional selection of thoughts, emotions, and behaviors based on current task demands and social context, and the concomitant suppression of inappropriate habitual actions" (Dixon, 2015). Interestingly, single-session cognitive enhancement activities like meditation have the potential to modulate cognitive control (Chan et al., 2017; Immink et al., 2017; Chan et al., 2018b; Chan et al., 2020; Hommel & Colzato, 2017). After single-session meditation, the effects can facilitate subsequent goal-directed activities like MSL tasks (Chan et al., 2017; Immink et al., 2017, Hommel & Colzato, 2017; Chan et al., 2018a; Chan et al., 2018b). Nevertheless, regarding the effects of meditation on cognitive control, two relevant points need to be considered. First, it is still unclear how different meditation types prime different cognitive control states that affect MSL (Chan et al., 2017; Chan et al., 2018b). Second, recent work discusses the role of effort (Immink et al, 2017; Jensen et al., 2011) during meditation, which affects subsequent tasks that rely on cognitive control (Immink et al., 2017; Chan et al., 2018b). Therefore, the aim of this study is to investigate whether different types of meditation alter cognitive control in distinct ways thereby influencing MSL and if effort modulates these relationships.

1.2 Cognitive Control and MSL

An important experimental paradigm to study MSL is the Discrete Sequence Production (DSP) task developed by Verwey (1999). In DSP task studies, participants are required to produce a discrete sequence of keypresses in response to a visual stimulus (Verwey, 1999; Abrahamse et al., 2013; Verwey & Dronkers, 2019; Verwey et al., 2020). In such experiments, participants normally follow a practice phase of ca. 500 repetitions per sequence. Additionally, the keys for each participant are usually counterbalanced to prevent effects of specific fingers in a certain position. Most importantly, the sequences remain discrete typically up to a maximum of seven key presses to enable participants to develop cognitive sequence representations (Chan et al., 2022). Besides the classic key-press DSP task, newer versions like the whole-body dance-step DSP task were developed (Chan et al., 2022).

To understand the cognitive processes underlying such MSL tasks, including cognitive control, more generally, Verwey et al. (2015) developed the Cognitive Framework for Sequential Motor Behaviour (C-SMB). A central component of the C-SMB are the independent processors necessary for motor execution. Each modality, for instance visual, auditory, verbal or manual, is assumed to encompass a set of three processors. First, the perceptual processor loads a representation of a stimulus into short-term memory (STM). Second, the central processor creates a motor representation from the stimulus representation and forwards it to the motor buffer. STM and motor buffer are closely linked to simultaneously hold overlapping features of the stimulus and motor representations. Third, the motor processor is responsible for retrieving the motor representation from the motor buffer and executing the physical movement. Over the course of a MSL task, performance becomes more automated since sequences become familiar. In that case, the central processor fetches the motor representation directly from long-term memory (LTM) and loads it into the motor buffer that is specific for the sequence to be executed (Verwey et al., 2015).

Well-learned movement sequences also follow a typical pattern of three phases (Abrahamse et al., 2013; Verwey et al., 2015). During the initiation phase, a sequence is selected by the central processor and loaded into the motor buffer before performing the first response of the sequence. This is characterised by longer response times (RT) compared to the following phases which require less processing. During the execution phase, motor responses are performed in a largely automated fashion, usually leading to short RT as no initiation and only minimal pre-processing is required for stimuli recognition. Lastly, the concatenation phase reflects the processing of a new chunk as the previous is completed, leading to moderate RT before returning to the quicker execution phase (Abrahamse et al., 2013; Verwey et al., 2015).

Considering the role of cognitive control within the C-SMB, it is suggested that two distinct motor learning strategies can be developed based on different cognitive control mechanisms (Verwey et al., 2015). In the external stimulus-based mode, cognitive control is executed through the central processor, which loads required information into STM. Further, control is determined by the stimuli, which are loaded into STM together with stimulus-response translation rules. At this point, movement elements are already pre-loaded into the motor buffer to enable quick reaction to stimuli. Accordingly, the learner can respond to a “stimulus in a reflex-like way”, which is also referred to as reaction mode (Verwey et al., 2015). In contrast, the internal plan-based mode does not depend on external stimuli but movement goals like internalised plans with successive movements based on sensory feedback. Usually, such plans consist of verbal and/or perceptual representations linked to movements (Verwey et al., 2015; Tubau et al., 2007). With continuous movement practice, such plans are substituted by coherent movement representations (Verwey et al., 2015). The distinction between external stimulus-based and internal plan-based cognitive control mechanisms demonstrates how different learning strategies can be employed during MSL but more importantly how cognitive control plays a crucial role in determining which motor learning strategies are utilised.

1.3 Focused Attention Meditation (FAM) and Attention in MSL

FAM is one common form of meditation whereby the subject is instructed to focus on a single object or sensation, usually the breath. Once the attention shifts elsewhere, often referred to as mind-wandering, the subject is supposed to re-focus on the original target object (Brandmeyer et al., 2019). In this case, cognitive control is utilised to narrow the attentional scope (Lippelt et al., 2014). Therefore, attentional mechanisms play a central role in FAM. Notably, research has shown that mindfulness, like FAM, has positive effects on various attentional functions such as the ability to attend to goal-directed activities faster (Moore & Malinowski, 2009). Furthermore, cognitive control is required to direct attention towards specific objects and maintaining that focus. Concerning that, meditators show better attentional control compared to non-meditators (Malinowski, 2013).

Meditation is known to also establish different mental states through its influence on cognitive control (Lippelt et al., 2014; Lutz et al., 2015; Chan et al., 2017; Hommel & Colzato, 2017; Chan et al., 2018b). Specifically, Hommel (2015) coined the term metacontrol, which refers to "the control of cognitive control" (Hommel & Colzato, 2017). Furthermore, metacontrol encompasses a continuum between persistence and flexibility. In the context of MSL, persistence means control from the goal representation and/or competition between decision alternatives. On the one hand, persistence is theoretically linked to the external stimulus-based mode of the C-SMB as it also suggests that control depends on the stimulus, which resembles a movement goal in DSP tasks (Verwey et al., 2015). On the other hand, competition between decision alternatives based on persistence could pertain to movement decisions or which movement information is attended to. According to Hommel & Colzato (2017), increased top-down control from the goal representation and competition between movement alternatives, would induce more selectivity in decision-making and more effective exclusion of irrelevant information. This would ultimately elicit a persistence metacontrol state (Hommel & Colzato, 2017). In line with the notion that meditation effects on cognitive control influence subsequent MSL tasks, Hommel & Colzato (2017) suggest that metacontrol states affect how following tasks are performed. Ultimately, they argue that FAM elicits a persistence metacontrol state as attention is biased towards a single goal, while competition between movement alternatives is strong, which leads to the exclusion of insignificant information. Thus, a persistence metacontrol state induced through FAM should evoke an external stimulus-based mode during the dance-step DSP task.

1.4 Open Monitoring Meditation (OMM) and Cognitive Flexibility in MSL

Besides FAM, OMM is another form of meditation that has received lots of attention in the literature (Lippelt et al., 2014; Lutz et al., 2015; Hommel & Colzato, 2017). During OMM, the subject keeps a broad attentional scope and merely monitors different bodily sensations that arise without concentrating on one in particular (Brandmeyer et al., 2019). Hence, cognitive control resources are needed to maintain a state in which attention is tonically activated for monitoring but not focal like in FAM. Fujino et al. (2018) also found that OMM reduces intentional focused attention and increases detachment from autobiographical memory, leading to a non-reactive attitude, a tendency that allows for the acceptance of new information.

In contrast to FAM, OMM is believed to bias metacontrol towards flexibility (Hommel & Colzato, 2017). Flexibility results in reduced top-down control from the goal representation and decreased competition between movement decisions. In this explorative state, decision-making is more complex and nuanced as further, potentially irrelevant, information is processed due to decreased selectivity. Conclusively, OMM is believed to induce a flexibility metacontrol state as attention is broad and the influence of goal-representations and competition between decision-alternatives weakened. Considering the C-SMB, this could give more room for the inclusion of sensory feedback and the development of verbal/perceptual representations linked to movement, which are characteristics of an internal plan-based approach (Verwey et al., 2015). Therefore, a flexibility metacontrol state induced through OMM could have the potential to evoke an internal plan-based strategy during the dance-step DSP task.

1.5 The Role of Effort in Cognitive Enhancement and MSL

Jensen et al. (2011) criticised that many of the studies investigating meditation and attention did not take task effort into account. Recently, a growing body of research has considered this criticism and included the role of effort for cognitive enhancement activities (Jensen et al., 2011; Lutz et al., 2015; Immink et al., 2017). Lutz et al. (2015) define effort as the “Phenomenal impression that one’s current mental state is easy or difficult to maintain”.

They further explain that high effort requires a deliberate intention of control, while low effort does not. They also suggest that it is hard to maintain high effort, since our resources of voluntary attention are limited (Lutz et al., 2015). In addition, Lutz et al. (2015) differentiate the role of effort for FAM and OMM practices by arguing that the strong focus on one object necessitates significant effort, while effort is reduced when no object selection is required. Within the context of motor learning, research by Immink et al. (2017) found that low effort predicted significantly shorter RT after FAM and OMM. For complex motor sequences however, only those participants who followed an OMM and experienced low effort reached a cognitive control state enabling shorter RT performance. In sum, it seems that effort potentially affects states of cognitive control, which is a central factor for successful motor learning.

1.6 The Present Study

The aim of this study is to investigate whether FAM and OMM alter cognitive control in distinct ways thereby influencing MSL and if effort modulates these relationships. Accordingly, an experimental study was designed in which participants followed either a FAM session, OMM session or listened to a podcast in the control condition and afterwards performed the dance-step version of the DSP task. At four moments during the experiment, effort was assessed using a questionnaire to estimate its effects during cognitive training on MSL performance. Regarding the effects of cognitive training on MSL, it was hypothesised that FAM and OMM modulate cognitive control differently and therefore lead to different MSL strategies (Hommel & Colzato, 2017; Immink et al., 2017; Verwey et al., 2015).

Specifically, it was expected that FAM evokes a persistence metacontrol state thereby inducing an external stimulus-based learning mode. As a persistence metacontrol state is characterised by an attentional focus on the goal representation and strong competition between movement alternatives (Hommel & Colzato, 2017) and an external stimulus-based learning strategy by a reaction mode (Verwey et al., 2015), the following was expected for the FAM group: Higher accuracy, shorter RTs, less concatenation, smaller learning improvement during training and shorter RT on unfamiliar sequences during testing compared to the OMM group.

Moreover, OMM was expected to elicit a flexibility metacontrol state thereby inducing an internal plan-based learning mode. As a flexibility metacontrol state is characterised by a weak influence of the goal representation and little competition between movement alternatives (Hommel & Colzato, 2017) and an internal plan-based learning strategy by an incorporation of sensory feedback and verbal and/or perceptual representations as part of plans (Verwey et al., 2015), the following was expected for the OMM group: Lower accuracy, longer RTs, more concatenation, larger learning improvement during training and longer RT on unfamiliar sequences during testing compared to the FAM group.

We also sought to understand if these effects are modulated by effort. Based on research by Immink et al. (2017), it was expected that effort after cognitive training is negatively correlated to learning improvement during the six training blocks.

2. Methods and Materials

2.1 Participants

48 students participated in this 2.5-hour study (23 females, $M_{age} = 21.9$, $SD_{age} = 3.0$, 38 self-reported right-footed, 3 comfortable with both feet). Their eligibility was based on the following inclusion criteria: age between 18 and 35 years, being meditation naïve, being non-smoker, no alcohol consumption in the last 24 hours before participation, having no physical injuries, learning disabilities, diagnosed mental health issues or neurological disorders, having not participated in any motor learning experiments involving dance-step MSL tasks and being healthy and feeling well. The study was approved by the ethics committee of the faculty of Behavioural, Management and Social Sciences (BMS) at the University of Twente (No. 220266). Participants received 3.5 credits in the university's credit system SONA after completion of their experimental session. In addition, the top three performers on the dance-step DSP task received 15€, 10€ and 5€ respectively.

2.2 Materials

The study was performed in an office of the BMS faculty at the University of Twente. Lighting conditions of the office were standardised and privacy of the participants during the experiment ensured. The experiment (cognitive training and dance-step DSP task) was run on an Alienware Windows 10 desktop computer, while participants filled in the questionnaires on an additional laptop. Participants followed the audio-guided cognitive task with wireless over-ear noise-cancelling headphones from Sony (WH-1000XM4) while sitting on a chair. The audios for the cognitive task were pre-recorded and had a length of roughly 22 minutes. Two audios were recorded by a professor and included instructions for either a FAM or OMM session (see Appendix A for an example). The audio for the control condition was a downloaded podcast episode about a topic related to neuroscience (see Appendix B).

The laptop with the questionnaire was placed on a desk in front of the participants. The chair was positioned roughly 100cm away from desk and participants could move the chair towards the desk to fill in the questionnaire. The main part of the questionnaire were Affect

Grid (Russell et al., 1989) and NASA Task Load Index (NASA-TLX) (Hart & Staveland, 1988; Hart, 2006) surveys to measure the variables pleasure, arousal, mental demand, physical demand, temporal demand, performance, effort and frustration. Most importantly, effort was assessed with the question “How hard did you have to work to accomplish your level of performance?” as part of the NASA-TLX. The other variables mentioned above are not addressed in this study. The questionnaire was administered via Qualtrics and split into four parts, which were carried out at four different moments: (1) Demographic data like age, dominant leg, gender, smoking, alcohol use and height. Affect Grid and NASA-TLX were administered for the first time. (2) Affect Grid and NASA-TLX plus a question about body weight. (3) Affect Grid and NASA-TLX. (4) Affect Grid, NASA-TLX and questions regarding the sequences the participants learned during the dance-step task, how they remembered the sequences, if they participated in similar studies before and experiences with learning sequences and gaming (see Appendix C for questionnaire).

The dance-step DSP task was performed on a commercially available dance mat (i.e. D-Force Non-Slip Pad, 93 x 81 cm) that was supported by rubber mats underneath to ensure safety and duct-taped to the floor to prevent unwanted movement. The mat was connected to the computer via a USB cable that was also taped to the floor for safety purposes. The JoyToKey Software Ver. 6.9.1 was used to connect the arrows on the mat to corresponding keys on the keyboard (forward to ‘w’, left to ‘a’, backward to ‘s’ and right to ‘d’). The front edge of the mat had approximately 120cm distance to the screen. The LG FLATRON full HD monitor W2442PE with a size of 24 inches and screen refresh rate of 60Hz was used for the dance-step DSP task. Instructions for the dance-step DSP task and experimental stimuli were presented on this monitor. The monitor could be adjusted in height and stood on fixated carton boxes on a desk to ensure that the stimuli were presented roughly at eye-level of the participants standing on the dance mat. The experiment was programmed with the E-Prime® software Ver. 2.0.10.356 (Psychology Software Tools, Inc., Sharpsburg, PA, USA). Two printed copies of the informed consent form (see Appendix D) were handed to each participant, one for the participant to take home and one for the researchers’ documentation.

2.3 Procedure

Most of the participants signed up for the experiment via SONA and selected a suitable timeslot for themselves, while some were contacted by the researchers. When participants arrived at the location for the experiment, they firstly were asked to read and sign the informed consent forms (all steps of the experiment are illustrated in Figure 1A). If they were eligible for participation, they received a short verbal introduction about the experiment.

To begin with, the participants had to fill in the first part of the questionnaire, which included a prompt on when to stop. Once participants completed this step, they were instructed to move back with the chair to its original position. The researcher then gave the participants the noise-cancelling headphones and instructed the participants to adjust them to their liking. Participants were required to sit straight, with both feet flat on the ground and hands comfortably placed on their thighs with the palms either facing up or down. In addition, the researchers explained to participants that they would listen to a roughly 22-minute long ‘audio’ or that they would do a ‘cognitive task’ or ‘cognitive training’, but consciously avoided the term ‘meditation’ at this point and throughout the whole experiment. This was done to ensure that participants did not develop any expectations regarding their participation in a meditation-related study. Finally, participants were required to close their eyes while listening to the audio and the researcher would be waiting outside. When participants finished listening to the audio, they were asked to take off the headphones and knock on the office door or open it. Then, the experimenter would enter the room again and ask the participants to fill in the second part of the questionnaire until prompted to stop again.

Afterwards, participants had to take of their shoes and step in the circle in the middle of the dance-mat facing the monitor. The researcher explained the nature of the task, that participants could start moving after the ‘+’ in the middle of the screen turned blue and that the top three performers would receive a cash price of 15€, 10€ and 5€ respectively. After starting the first of six training blocks on the computer, the researcher left the room again and participants would knock or open the door again once they were finished. Each training block included a 30-second break halfway through the block. Moreover, there was a 3-minute break after each block and a 10-minute break after the third. During this break, participants were also required to fill in the third part of the questionnaire. Then, another three training blocks with 3-minute breaks in between would follow. After completion of all training blocks, participants filled in the fourth part of the questionnaire. Finally, they were asked to complete two more testing blocks with a 3-minute break in between. The time investment for each participant in the experiment was roughly 2.5 hours in total and remaining questions of the participants were answered at the end of the study.

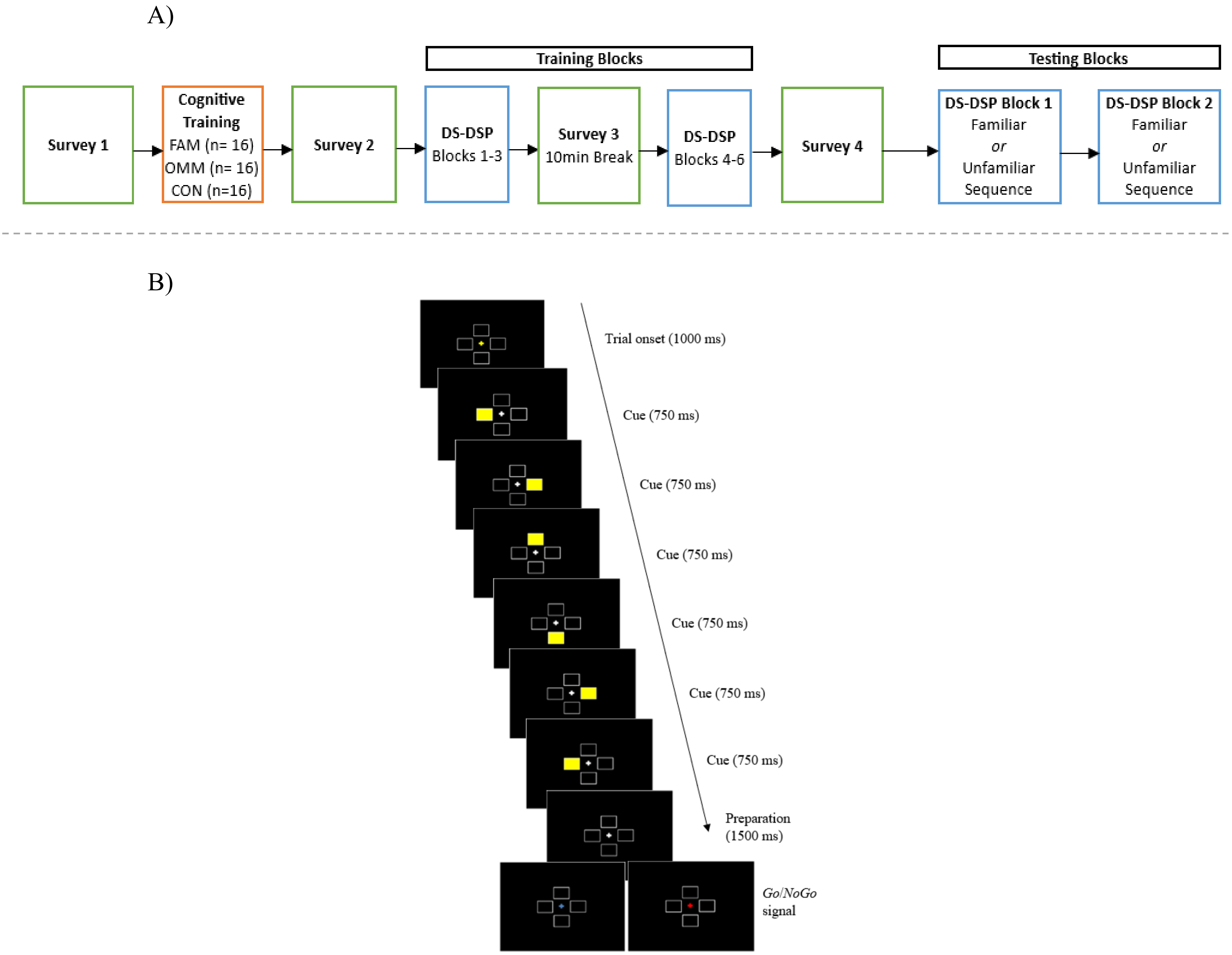

Figure 1. A) Flow chart of the experimental procedure including survey tasks (green), cognitive task (orange) and dance-step DSP tasks (blue). The sequence in test block 2 was unfamiliar if the one in test block 1 was familiar and vice versa. **B)** Example of the cues for a regular 6-step trial of the dance-step DSP task including cueing times and Go/NoGo signals. From *The Discrete Sequence Production Task in the Form of a Step Task: An Application of Individual Exponential Learning Curves in Motor Sequence Learning*, by E. Wiechmann, 2021, University of Twente (https://essay.utwente.nl/87430/1/Wiechmann_BA_BMS.pdf).

2.4 Dance-Step DSP Task

Participants of the FAM, OMM and control conditions performed the dance-step version of the DSP task for a total of eight blocks, namely six training and two testing blocks. Each participant practiced two 6-step sequences that were predetermined based on the participant number. In each block, the sequences appeared in random order and were repeated 24 times (48 trails per block), leading to a total of 288 practice trials across the six training blocks, so 144 per sequence. The sequences "were counterbalanced by rotating the steps within each sequence" (Veith, 2022). Therefore, eight participants were needed for one fully counterbalanced dataset. In addition, the two testing blocks were also counterbalanced. They included one block with the two familiar sequences and one with two unfamiliar sequences. Half of the participants were tested on the familiar sequences first, the other half on the unfamiliar. Furthermore, unfamiliar sequences are solely defined by their unfamiliar nature to the participant. In general, these sequences are not entirely new, but were used with other participants, which means that the sequences just have been reorganized in a way that each familiar sequence was unfamiliar to another participant and vice versa (counterbalancing).

A regular 6-step trial of the dance-step DSP task included a 1000ms onset phase, six 750ms cues for the steps, a 1500ms preparation phase and a Go (blue) or NoGo (red) signal (Wiechmann, 2021), which is also depicted in Figure 1B. After each trial, participants received feedback. If the sequence was performed accurately a 'Good!' was displayed on screen. If mistakes were made after taking six steps, each inaccurate step was named in successive fashion. Lastly, a 'Too early!' message was displayed if participants started moving before the Go signal.

1.5 Data Analysis

The data was analysed with linear mixed effects regression (LMER) models of the lme4 package Ver. 1.1-33 (Bates et al., 2014) in RStudio Ver. 2023.03.1+446 (RStudio Team, 2020) (see Appendix E for R code). In contrast to normal ANOVA models, LMER allows for including subject-based random factors to analyse group effects on reaction times (Chan et al., 2018b; Veith, 2022). The main trial-based models included reaction time and accuracy as dependent variable and group (FAM, OMM, control), training block (1-6), familiarity of test sequences (familiar, unfamiliar) as independent variables. Additionally, step-based models included RT as outcome variable and group (FAM, OMM, control), training block (1-6) and sequence step (1-6) as predictors. Further, percentage decrease in RT between training blocks 1 and 6 was modelled as outcome variable based on group (FAM, OMM, control) as predictor.

Next, effort was treated as dependent variable and modelled against group (FAM, OMM, control) and measurement point (baseline, after cognitive training, after 3 training blocks and after 6 training blocks) as independent variables. Lastly, correlations between percentage decrease in RT and effort after cognitive training were run. ANOVA results of the LMER models include type II Wald chi square tests with an alpha level of 0.05. As the group variable (FAM, OMM, control) was the central manipulation of the study, mainly group effects and interactions including the group variable are presented in the results.

3. Results

3.1 Accuracy and RT

LMER model analysis of the trial-level dance-step motor learning data revealed the following results for accuracy, which was considered as an outcome variable with Group (FAM, OMM, control) and Block (1-6) as predictors. The effect of Group on accuracy was not significant, $\chi^2(2, n = 48) = .47$, $p = .79$, meaning that the accuracy of the groups did not differ in general. However, the Block x Group interaction was significant, $\chi^2(10, n = 48) = 24.72$, $p = .006$, which highlights that accuracy developed differently for the groups across six training blocks (Figure 2A).

Next, RT was modelled after exclusion of inaccurate trials during training (15.52%) and testing (18.84%) blocks and the exclusion of accurate trials more than 2.5 standard deviations away from the mean. By excluding these observations, the focus was directed towards correct full sequences performed within a normal timeframe. Group (FAM, OMM, control) and Block (1-6) were the independent variables. During the six training blocks, the effect of Group (FAM, OMM, control) on RT was not significant, $\chi^2(2, n = 48) = .53$, $p = .77$, meaning that the RT of the different groups did not differ in general. However, the Block x Group interaction was significant, $\chi^2(10, n = 48) = 157.85$, $p < .001$, which highlights that motor learning practice across six blocks differed between the groups (Figure 2B).

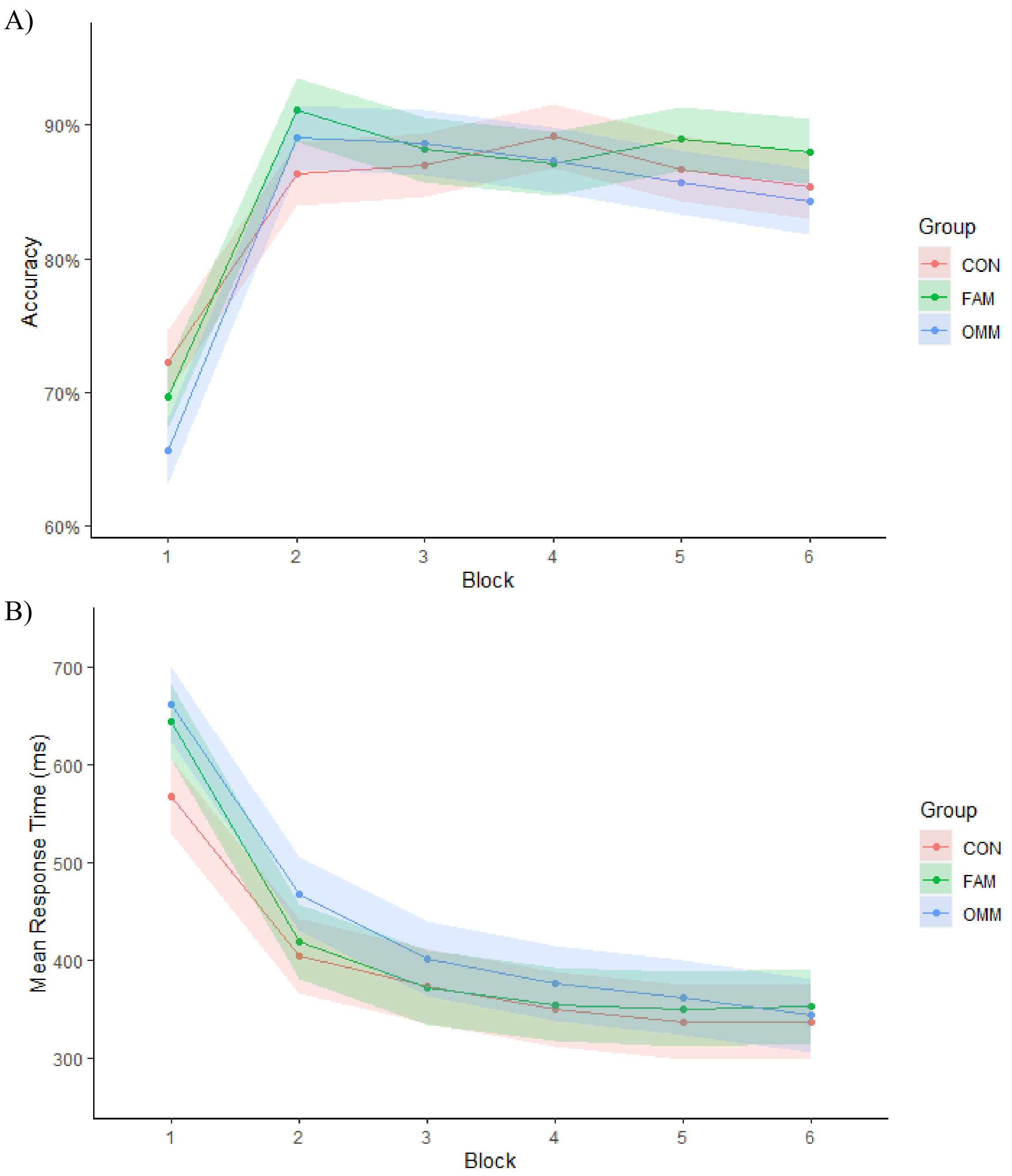

Figure 2. A) Accuracy of the three groups (FAM, OMM, control) over six training blocks on the dance-step DSP task. The three groups showed a different development of accuracy over six training blocks. Naturally, accuracy improved for all groups in the second block. However, their trajectories differed from there. For the OMM group, a steady decline in accuracy for all following training blocks was observed. Accuracy of the FAM group decreased until Block 4, rose during Block 5 and fell again in Block 6. The control group's accuracy improved until finishing Block 4 and declined again afterwards. Error bars represent 95% confidence intervals. **B)** Mean RT of the three groups (FAM, OMM, control) over six training blocks on the dance-step DSP task. The three groups showed different learning patterns. The OMM group had longer RTs during the first blocks and needed five or six practice blocks to catch up with the other groups, eventually overtaking the FAM group in Block 6. The FAM group had longer RTs than the control group but caught up during the second block already. The control group started with a mean RT below 600ms but failed to maintain shorter RTs with increasing practice compared to the other groups. Error bars represent 95% confidence intervals.

3.2 Concatenation

Besides trial-based dance-step data where RT was analysed per trial, step-based training data was investigated as well to understand RT per step. After exclusion of inaccurate trials, RT was modelled as outcome variable and Group (FAM, OMM, control), Block (1-6) and Sequence step (1-6) as predictors. The Group x Block x Sequence step interaction yielded significant results, $\chi^2(50, n = 48) = 114.74$, $p < .001$, highlighting that the different RTs per group developed differently over the six training blocks (Figure 3; Table 1). Therefore, each group seemed to learn the steps, making up the whole sequences, in a different manner during training.

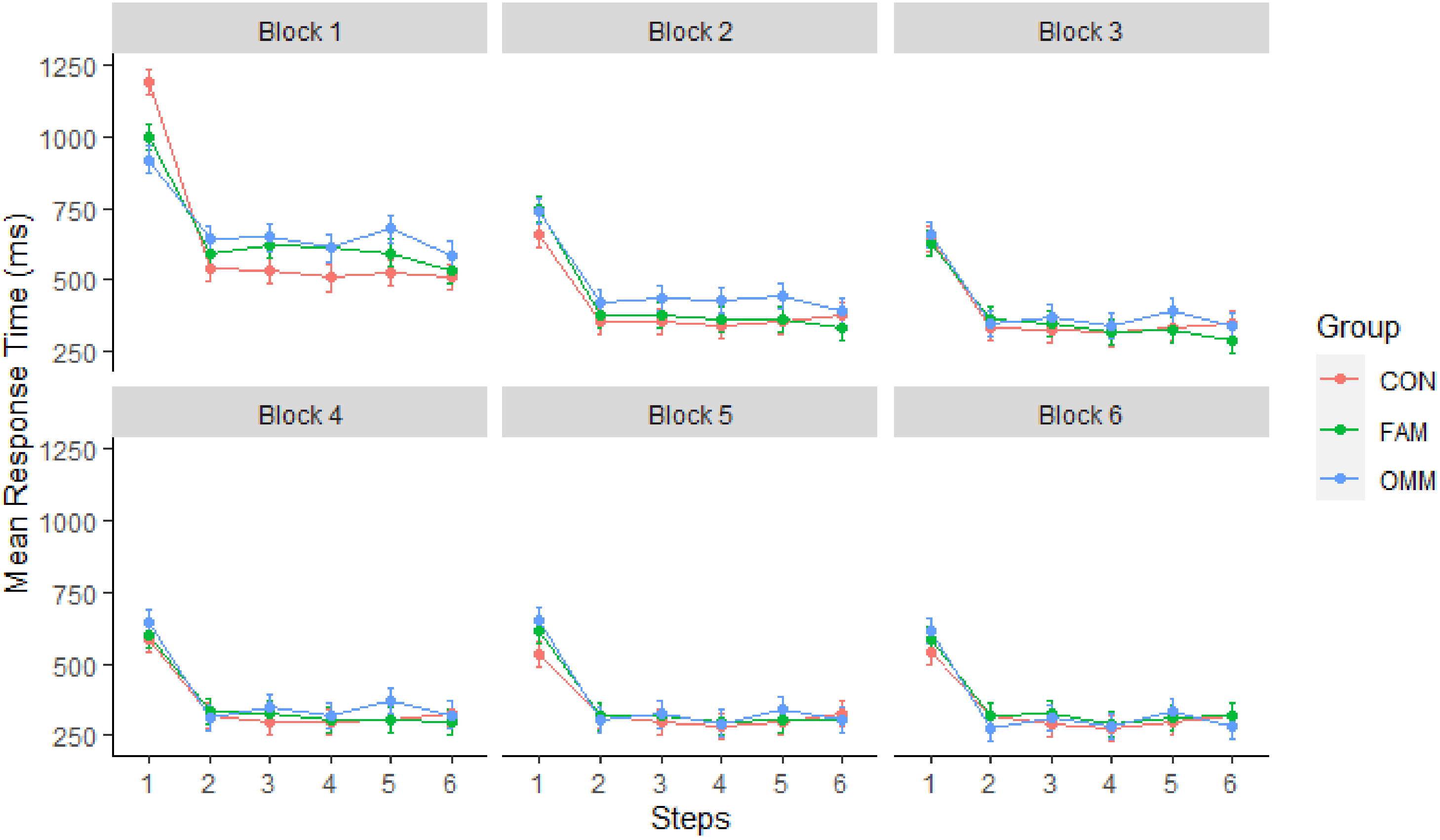

Figure 3. Mean RT of the three groups (FAM, OMM, control) for each step of the dance-step DSP task per block. RT patterns developed differently per group over the six training blocks. These differences are recognisable especially during the first two blocks. The control group needed longer to initiate the first step but had shorter RT on the following steps during the first block. The general patterns for the FAM and OMM groups seemed to develop during the first block already. In Block 2, RT for all group declined, while the OMM group seemed to have consistently longer RT on most steps compared to the other groups. From Blocks 3 to 6, RT for all groups declined further, but did not differ much anymore. Error bars represent 95% confidence intervals.

Block	Group	Step 3-4		Step 4-5		Step 5-6	
		F-Value	P-Value	F-Value	P-Value	F-Value	P-Value
1	FAM					5.437	0.02 *
2	FAM					6.126	0.01 *
3	FAM	6.365	0.01 *			16.82	<0.001 ***
4	FAM	4.802	0.029 *				
5	FAM	3.896	0.049 *				
6	FAM	11.67	<0.001 ***				
1	OMM			7.273	0.007 **	13.13	<0.001 ***
2	OMM					11.6	<0.001 ***
3	OMM	6.49	0.011 *	21.36	<0.001 ***	15.4	<0.001 ***
4	OMM			11.74	<0.001 ***	11.78	<0.001 ***
5	OMM	8.287	0.004 **	20.21	<0.001 ***	10.48	0.001 **
6	OMM	7.24	0.007 **	21.55	<0.001 ***	21.58	<0.001 ***
1	CON						
2	CON						
3	CON						
4	CON						
5	CON					4.354	0.037 *
6	CON			4.184	0.041 *		

Table 1. Significant one-way ANOVA results for Steps 3-4, 4-5 and 5-6 per Group (FAM, OMM, control) and Block (1-6). Guided by the C-SMB and for the brevity of this report, we focused on planned comparisons of these steps to detect concatenation. In combination with Figure 3, the FAM group significantly shortened its RT between Steps 5 and 6 during the first two blocks. However, from Blocks 3-6 RT become significantly longer on Step 3. The OMM group showed significant alterations between shorter (Steps 4 and 6) and longer (Step 5) RT under consideration of Figure 3. The control group did only show few significant differences in RT between steps.

3.3 Familiar vs. Unfamiliar Sequences in Test Blocks

For the two test blocks, a significant difference between familiar and unfamiliar sequences on RT was found, $\chi^2(1, n = 48) = 655.58, p < .001$, whereas the effect of group (FAM, OMM, control) was not significant, $\chi^2(2, n = 48) = .61, p = .74$, indicating similar performance of the groups. Nevertheless, the familiar vs. unfamiliar x group interaction was significant, $\chi^2(2, n = 48) = 38.32, p < .001$, which shows that the groups differed in their performance of familiar and unfamiliar sequences during the test blocks (Figure 4).

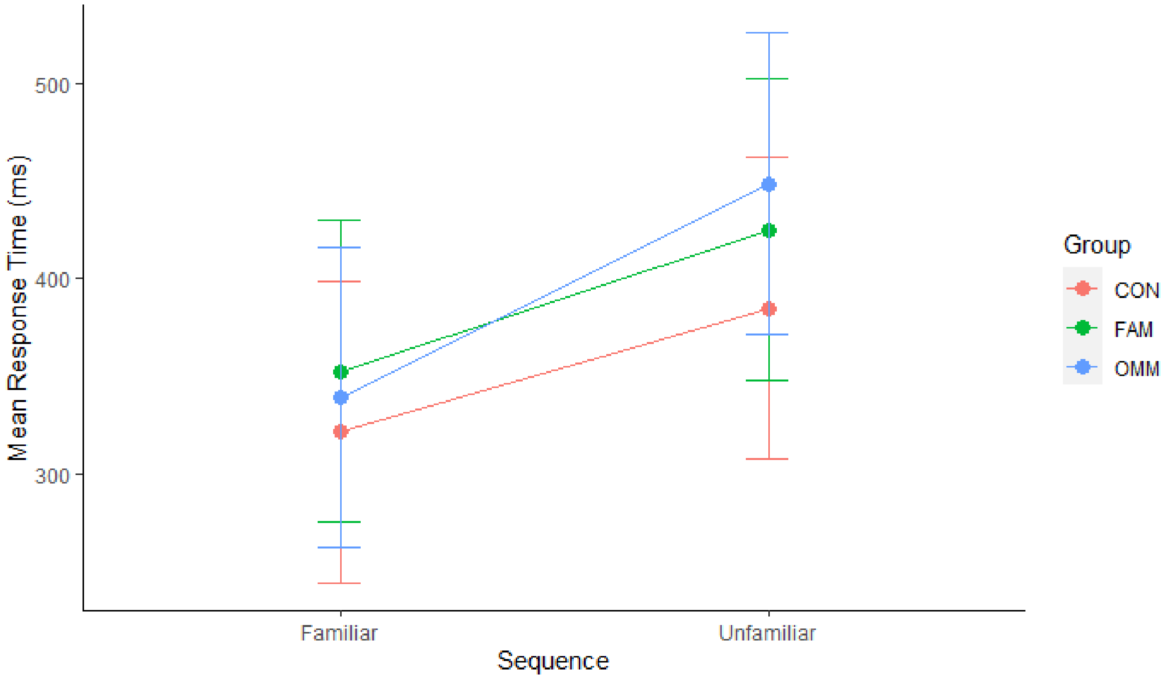

Figure 4. Mean RT of the three groups (FAM, OMM, control) during two test blocks of the dance-step DSP task, one with familiar and one with unfamiliar sequences. For all groups, familiar sequences had shorter RT than unfamiliar sequences, whereas both FAM and OMM had longer RT on unfamiliar sequences compared to control and OMM longer RT than FAM. The RT difference between familiar and unfamiliar sequences was largest for the OMM group. Error bars represent 95% confidence intervals.

3.4 RT Improvement During Training Blocks

For the trial-based dance-step data, the percentage decrease in RT between the first and sixth block were calculated to be able to conduct a subsequent correlational analysis with effort. When Group (FAM, OMM, control) was used to predict RT percentage decrease between Blocks 1 and 6, significant results were obtained, $\chi^2(2, n = 48) = 8.02, p = .02$. Thus, the decrease in RT from Blocks 1 to 6, indicative of MSL, was different between groups. While the FAM and control group both had a mean decrease in RT of roughly 50% between Blocks 1 and 6, the OMM group had a larger mean RT decrease of roughly 57%.

3.5 Effort During Cognitive Training and its Effects on MSL

The Measure x Group interaction for effort was significant, $\chi^2(6, n = 48) = 12.91$, $p = .044$, illustrating that effort was rated differently between the groups depending on the task they performed beforehand (Figure 5A). In the case of effort, planned comparisons highlighted significant contrast differences between control and FAM groups, $t(180) = -4.81$, $p = .01$, and control and OMM groups, $t(180) = -4.56$, $p = .02$, at the second measurement point (post cognitive training). Therefore, effort was perceived differently between control and FAM and control and OMM groups, underlining there were differences in terms of effort between meditation and listening to a podcast.

Additionally, Spearman's rank correlation was computed to assess the relationship between effort after cognitive training and the percentage of RT decrease between Blocks 1 and 6. There was a significant positive correlation between these two variables, $r(46) = .31$, $p = .03$ (Figure 5B). Thus, the effort perceived during cognitive training was positively related to the improvement during the motor learning task.

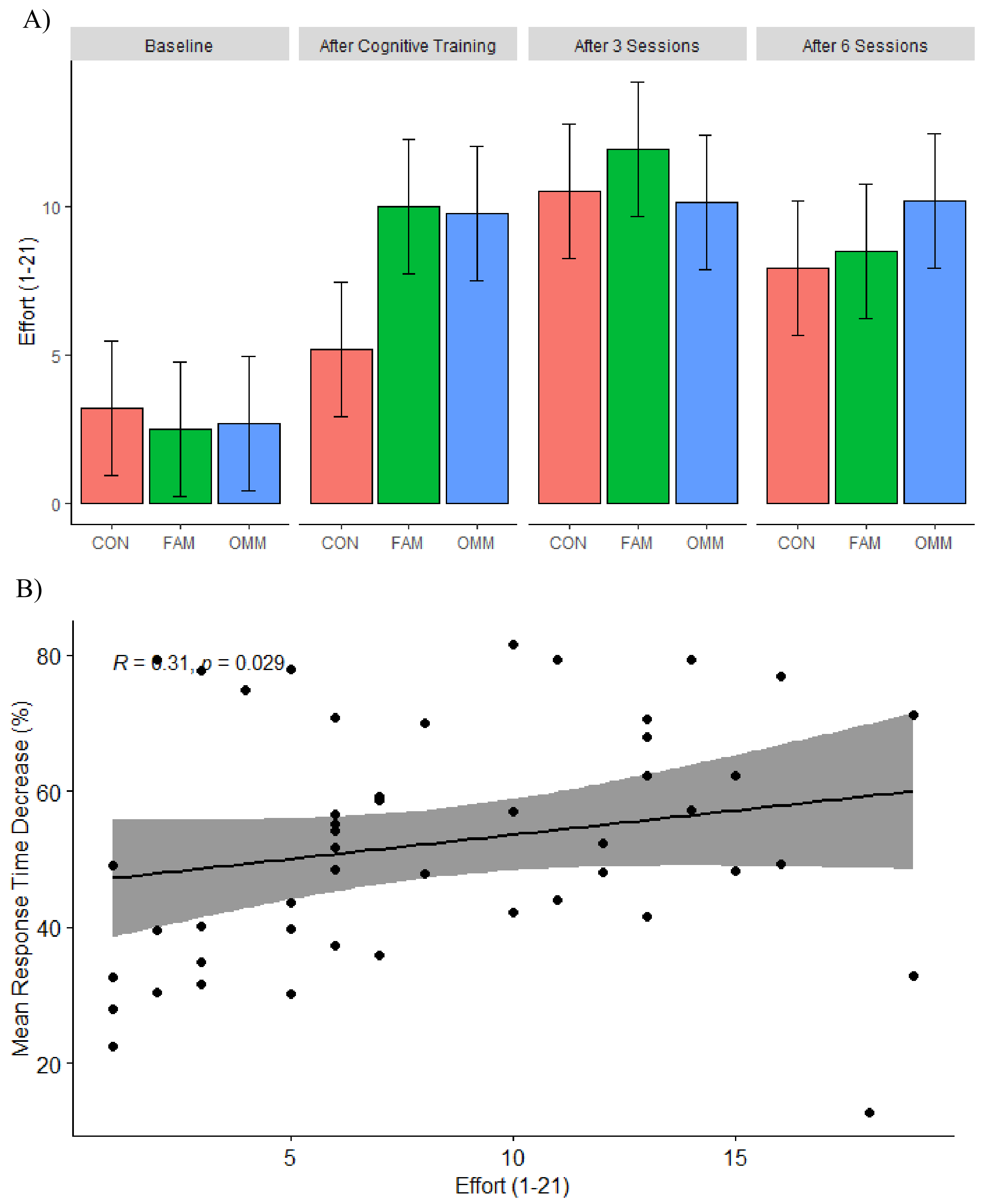

Figure 5. A) Effort ratings from the NASA-TLX at four different measurement points per group (FAM, OMM, control). At baseline, effort ratings were similar for all groups. After cognitive training though, effort ratings increased much more for the FAM and OMM conditions compared to the control condition. After three training blocks on the motor learning task however, the control group's effort ratings rose to the level of the FAM and OMM groups. While effort decreased slightly for the control and FAM groups after six training blocks, the OMM group did not experience any change in effort between meditation and motor learning tasks. Error bars represent 95% confidence intervals. **B)** Scatterplot for the correlation between effort ratings after cognitive training and mean RT decrease between training Blocks 1 and 6 (see chapter 3.4). Higher effort after cognitive training related to greater MSL improvements during training on the dance-step DSP task.

4. Discussion

This study investigated whether FAM and OMM alter cognitive control in distinct ways thereby influencing MSL and if effort modulates these relationships. It was expected that FAM evokes a persistence metacontrol state leading to an external stimulus-based learning mode during MSL. Moreover, OMM was expected to elicit a flexibility metacontrol state thereby inducing an internal plan-based strategy during MSL. Overall, the presented results have highlighted numerous distinct differences between FAM and OMM groups on the dance-step DSP task, supporting the idea that cognitive control was modulated in different ways after FAM and OMM.

In specific, it was shown that the OMM group declined in accuracy, that it had longer RT before eventually having shorter RT than the FAM group during the last training block, that it concatenated more, that RT slowed down more on unfamiliar sequences and that RT improvement was 7% larger during training compared to FAM. Considering the metacontrol hypothesis by Hommel & Colzato (2017), OMM therefore biased participants towards a flexibility metacontrol state characterised by weak directivity from goal representations and little conflict between information and movement alternatives. First, the OMM group had longer RT during most of the training and made more mistakes illustrating the weak influence of goal representations and the more elaborate processing of additional information. This is supported by Fujino et al. (2018), who found that OMM leads to a non-reactive attitude. Second, the repeated concatenation compared to the FAM group further suggests a more elaborate and continuous processing of movement information. Third, in line with previous work (Abrahamse & Noordzij, 2011; Immink et al., 2017), the OMM group developed a comparatively solid sequence representation during training, making it more difficult to switch to unfamiliar sequences and resulting in longer RT. This aligns with evidence from the SRT literature where longer RT on the transfer block highlight a stable sequence representation of previously learned sequences (Immink et al., 2017, Chan et al., 2018b). The development of a solid sequence representation due to the more extensive processing of information also enabled the shorter RT of the OMM group in the last training block compared to the FAM group. In support of that, Verwey et al. (2015) argue that well-learned sequences become more automated as motor representations can be loaded into the motor buffer directly from LTM by the central processor.

Conclusively, it can be argued that the OMM group followed an internal plan-based strategy during the dance-step DSP task. Since the C-SMB suggests that goals consist of plans with successive movements based on sensory feedback and that such plans can incorporate verbal and/or perceptual representations linked to movements (Verwey et al., 2015), it shows how more information is processed compared to an external stimulus-based mode. While we cannot prove what kinds of information were processed by the OMM group during MSL, the evidence suggests that a more explorative and elaborate strategy was followed before developing a strong sequence representation and overtaking the FAM group. Hence, it seems likely that the OMM group followed an internal plan-based strategy. Ultimately, the hypothesis that OMM elicits a flexibility metacontrol state thereby inducing an internal plan-based strategy during MSL was therefore accepted.

The FAM group made mistakes as well but was also able to increase accuracy again during training, had shorter RT for most of the MSL training, concatenated less, had shorter RT on unfamiliar sequences and showed less improvement during training compared to the OMM group. Considering the metacontrol hypothesis, FAM biased participants towards a persistence metacontrol state characterised by strong influence from goal representations and increased conflict between information and movement alternatives resulting in heightened selectivity (Hommel & Colzato, 2017). First, the FAM group had shorter RT for most of the training phase due to strong influence from the stimulus representation leading to a narrow attentional scope and indifference towards additional information. Second, the results showed that the FAM group concatenated once during sequence performance, which further supports the idea that less information was processed compared to the OMM group who concatenated on Steps 3 and 5. Third, the FAM group did not develop such a solid sequence representation compared to the OMM group, illustrated by the shorter RT on unfamiliar sequences, the smaller RT difference between familiar and unfamiliar sequences and the closer resemblance of general learning effects of the control condition during training (Abrahamse & Noordzij, 2011; Immink et al., 2017). Thus, the FAM group merely needed to re-direct its attentional scope to a new set of stimuli (Moore & Malinowski, 2009; Lippelt et al., 2014) when unfamiliar sequences were presented during testing, while the OMM group needed to process a whole new array of information.

Conclusively, it can be argued that the FAM group followed an external stimulus-based approach during MSL in line with previous studies (Chan et al., 2017; Chan et al., 2018). According to the C-SMB, in the stimulus-based mode control is exerted by a set of stimuli whose representation is loaded into STM together with stimulus-response translation rules, while movement representations are pre-loaded into the motor buffer (Verwey et al., 2015). This illustrates how a more immediate connection between stimulus and response is formed without much processing of additional features, thereby enabling shorter RT during MSL. As this is reflected in the results of the FAM group, it was replicated that it followed an external stimulus-based approach during MSL (Chan et al., 2017; Chan et al., 2018). Ultimately, the hypothesis that FAM elicits a persistence metacontrol state thereby inducing an external stimulus-based strategy during MSL was accepted.

Furthermore, it was expected that effort after cognitive training negatively correlates with MSL improvement (Immink et al., 2017). However, the significant correlation between effort and RT improvement between the first and last training blocks was positive in this study. Thus, higher effort during cognitive training was related to increased MSL improvements, which led to the rejection of the last hypothesis. Additionally, the results of this study contradict with the findings of Immink et al. (2017), who found that low effort predicted enhanced motor learning performance, since meditation and control groups differed on perceived effort after cognitive training but performed quite similarly after six training sessions on the dance-step DSP task.

Potentially, the different results of this study and the one by Immink et al. (2017) regarding effort can be explained by the nature of the experimental task. During the SRT task used by Immink et al. (2017), the control group had longer RT than the meditation groups, while the control group had the shortest RT in the dance-step DSP task of this study. Previous research has further argued that FAM groups should resemble the normal learning effects of control groups more closely compared to OMM (Abrahamse & Noordzij, 2011; Immink et al., 2017). Whereas this group difference was supported by the present results of the DSP task, control and FAM groups differed the most on the SRT task of Immink et al. (2017). Since performance of FAM, OMM and control groups seems to differ on DSP and SRT tasks, effort could also modulate these effects in different ways. As effort during meditation affected MSL performance in line with previous work (Jensen et al., 2011; Lutz et al., 2015), the ultimate effects of effort during subsequent activities could be determined by task characteristics, thereby influencing performance improvement positively on DSP tasks and negatively on SRT tasks. Certainly, further research is needed to understand how effort modulates cognitive control during meditation and how this affects following goal-directed activities.

4.1 Limitations, Implications and Future Research

In the present study, participants followed a single meditation session of roughly 22 minutes. While this was enough to observe distinct effects on cognitive control, these should become more pronounced with increased practice (Lutz et al., 2015). Thus, it is unclear to what extent effects on cognitive control were sustained beyond the experiment or if a different training paradigm would have influenced the results. For instance, whether a single but longer meditation session or a repeated practice over multiple days before engaging in MSL would have made a difference. In sum, future research should consider varying training paradigms and the resulting effects on cognitive control.

A similar argument can be brought forward when considering the MSL training phase. In the present study, two sequences were practiced in random order with 144 repetitions per sequence. While this was sufficient to retain distinct learning effects in a sample of healthy students, older populations might need a more extensive practice to gain similar learning outcomes (Chan et al., 2023; Barnhoorn et al., 2019). At the same time, an expanded practice could lead to boredom and loss of attention in participants, which highlights the necessity of appropriate practice quality and quantity for different target groups, such as the elderly, in future research (Chan et al., 2023).

Lastly, our findings imply that although performance of all groups was quite similar at the end of training, cognitive control states are a crucial component in MSL as they influence how a goal-directed activity is approached. As outlined before, the OMM group processed more information during MSL and was therefore able to develop a solid sequence representation, which could have important implications for MSL in the elderly (Chan et al., 2023). In that regard, Chan et al. (2023) argue that the natural deterioration of (sub-)cortical structures with increasing age lead to increased cognitive control states similar to those after FAM, which is not ideal for MSL in the elderly. However, a weakened cognitive control state induced by OMM might be more beneficial for motor sequence acquisition in older participants because of the successful integration of additional movement information based on an exploratory stance during MSL (Chan et al., 2023). Thus, MSL would be enhanced in the elderly due to the development of solid sequence representations enabling them to learn sequences effectively. Ultimately, this could help older people to maintain independence and quality of life. Therefore, future research should address cognitive enhancement activities for MSL in the elderly.

4.2 Conclusion

The aim of this study was to investigate whether FAM and OMM alter cognitive control in distinct ways thereby influencing MSL and if effort modulates these relationships. Results showed that after OMM, participants started with longer RT, continued to make mistakes, concatenated more, had longer RT on unfamiliar sequences and greater RT improvement during training compared to FAM and the control condition. Therefore, FAM and OMM modulated cognitive control in distinct ways. It was found that FAM evokes a persistence metacontrol state thereby inducing an external stimulus-based strategy during MSL, while it was suggested that OMM biased participants towards a flexibility metacontrol state thereby eliciting an internal plan-based approach to MSL. Opposed to previous work, results revealed a positive correlation between effort during cognitive enhancement and MSL improvements. Despite similar performance of OMM and FAM groups at the end of training, the findings highlight that cognitive control has a crucial influence on how MSL is approached. On that note, OMM might be especially beneficial for motor sequence acquisition in older populations and future research should therefore consider cognitive enhancement for MSL in the elderly.

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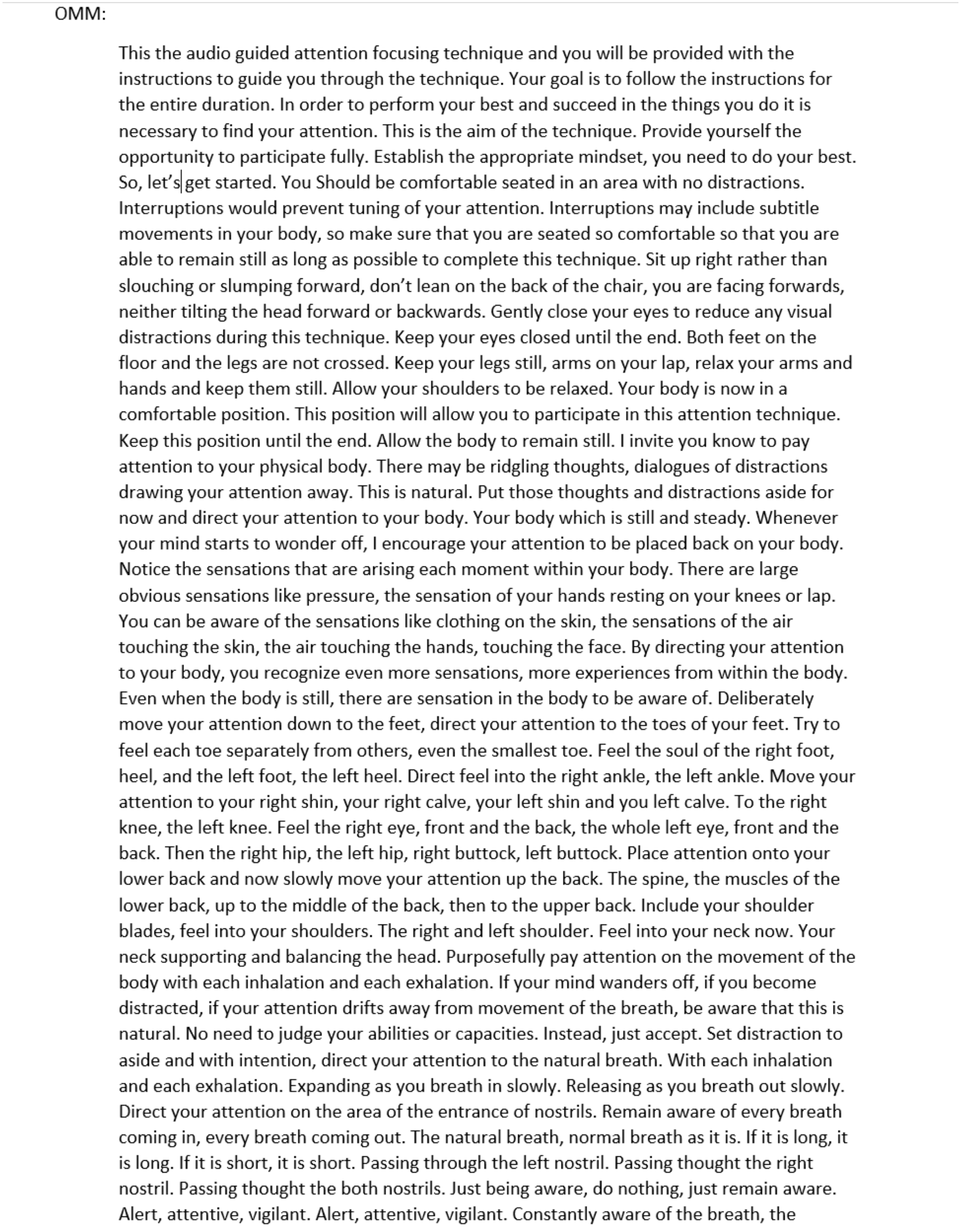
Appendix A

Transcript of OMM Audio



OMM:

This the audio guided attention focusing technique and you will be provided with the instructions to guide you through the technique. Your goal is to follow the instructions for the entire duration. In order to perform your best and succeed in the things you do it is necessary to find your attention. This is the aim of the technique. Provide yourself the opportunity to participate fully. Establish the appropriate mindset, you need to do your best. So, let's get started. You Should be comfortable seated in an area with no distractions. Interruptions would prevent tuning of your attention. Interruptions may include subtitle movements in your body, so make sure that you are seated so comfortable so that you are able to remain still as long as possible to complete this technique. Sit up right rather than slouching or slumping forward, don't lean on the back of the chair, you are facing forwards, neither tilting the head forward or backwards. Gently close your eyes to reduce any visual distractions during this technique. Keep your eyes closed until the end. Both feet on the floor and the legs are not crossed. Keep your legs still, arms on your lap, relax your arms and hands and keep them still. Allow your shoulders to be relaxed. Your body is now in a comfortable position. This position will allow you to participate in this attention technique. Keep this position until the end. Allow the body to remain still. I invite you know to pay attention to your physical body. There may be ridgling thoughts, dialogues of distractions drawing your attention away. This is natural. Put those thoughts and distractions aside for now and direct your attention to your body. Your body which is still and steady. Whenever your mind starts to wonder off, I encourage your attention to be placed back on your body. Notice the sensations that are arising each moment within your body. There are large obvious sensations like pressure, the sensation of your hands resting on your knees or lap. You can be aware of the sensations like clothing on the skin, the sensations of the air touching the skin, the air touching the hands, touching the face. By directing your attention to your body, you recognize even more sensations, more experiences from within the body. Even when the body is still, there are sensation in the body to be aware of. Deliberately move your attention down to the feet, direct your attention to the toes of your feet. Try to feel each toe separately from others, even the smallest toe. Feel the soul of the right foot, heel, and the left foot, the left heel. Direct feel into the right ankle, the left ankle. Move your attention to your right shin, your right calve, your left shin and you left calve. To the right knee, the left knee. Feel the right eye, front and the back, the whole left eye, front and the back. Then the right hip, the left hip, right buttock, left buttock. Place attention onto your lower back and now slowly move your attention up the back. The spine, the muscles of the lower back, up to the middle of the back, then to the upper back. Include your shoulder blades, feel into your shoulders. The right and left shoulder. Feel into your neck now. Your neck supporting and balancing the head. Purposefully pay attention on the movement of the body with each inhalation and each exhalation. If your mind wanders off, if you become distracted, if your attention drifts away from movement of the breath, be aware that this is natural. No need to judge your abilities or capacities. Instead, just accept. Set distraction to aside and with intention, direct your attention to the natural breath. With each inhalation and each exhalation. Expanding as you breath in slowly. Releasing as you breath out slowly. Direct your attention on the area of the entrance of nostrils. Remain aware of every breath coming in, every breath coming out. The natural breath, normal breath as it is. If it is long, it is long. If it is short, it is short. Passing through the left nostril. Passing thought the right nostril. Passing thought the both nostrils. Just being aware, do nothing, just remain aware. Alert, attentive, vigilant. Alert, attentive, vigilant. Constantly aware of the breath, the incoming breath, the outgoing breath, the incoming breath, the outgoing breath. Keep your attention vastly fixed at the entrance of the nostrils. Like a gate keeper, like a watchman, aware of every breath entering the nostrils, aware of every breath moving out of the nostrils. Alert, attentive, vigilant. The natural breath, the normal breath as it is. If it is long, it is long, if it is a short it is short, passing through the left nostril, the left nostril, passing through the right nostril, the right nostril, passing though both nostrils, both nostrils. Just being aware, do nothing, remain aware. Alert, attentive, vigilant. Remain alert, attentive, vigilant. Constantly aware of the breath, the incoming breath, the outgoing breath, the incoming breath, the outgoing breath. Aware of every breath entering the nostrils, aware of every breath moving out of the nostrils. Incoming breath, outgoing breath, natural breath, pure breath, nothing but the breath. Now that you have placed your attention on your breath, expand the focus of your attention, such that now you are aware of your breath and your body. There is no separation Between the breathing and the body. Your attention may naturally be drawn by different sensations in your body, be aware of them and not to judge them. Without reacting or changing experience, lets us just watch and observe the sensation and how we react to the sensation. At this stage your attention is becoming more open and inclusive. Your experience is far reaching combining your body, breath and sounds. You are also aware of thoughts, have a sense that your thoughts, all your sensations all of your experiences are like a stream, a stream flowing over time and observe this stream like a stream of water. See the entire stream of these experiences. Watching the stream go by imagine that your thoughts, feelings and sensations are all floating in the stream, you can see them. You recognize them, some of them maybe new, some may be surprising, some may be ordinary. Some may want to linger. Some may wish to go by quickly. All of this you can watch and you are an observer. See what comes with the stream and see what goes with the stream. The comings and goings of thoughts feelings and sensation. Watch them like an observer watching the stream. And at this stage, you begin to prepare to complete this attention technique. Let go of the previous activity completely, as of now you start to prepare of what is coming next. Remember that you have been practicing an attention technique and it is coming to an end. Draw your attention and become aware of your surroundings. Recall where are you seated, and when you are ready, you can start to introduce some small movements into your toes, into your fingers, your wrists, your neck, and gradually introduce more and more movement in your body. If you kept your body still, you can now move it. Very gently as well, open your eyes accustom your vision to the lighting in the room. Move as you like, stretch your arms, no rush, take your time. And now we have come to the end and you have completed the attention focusing technique. You can proceed with your next set of activities.

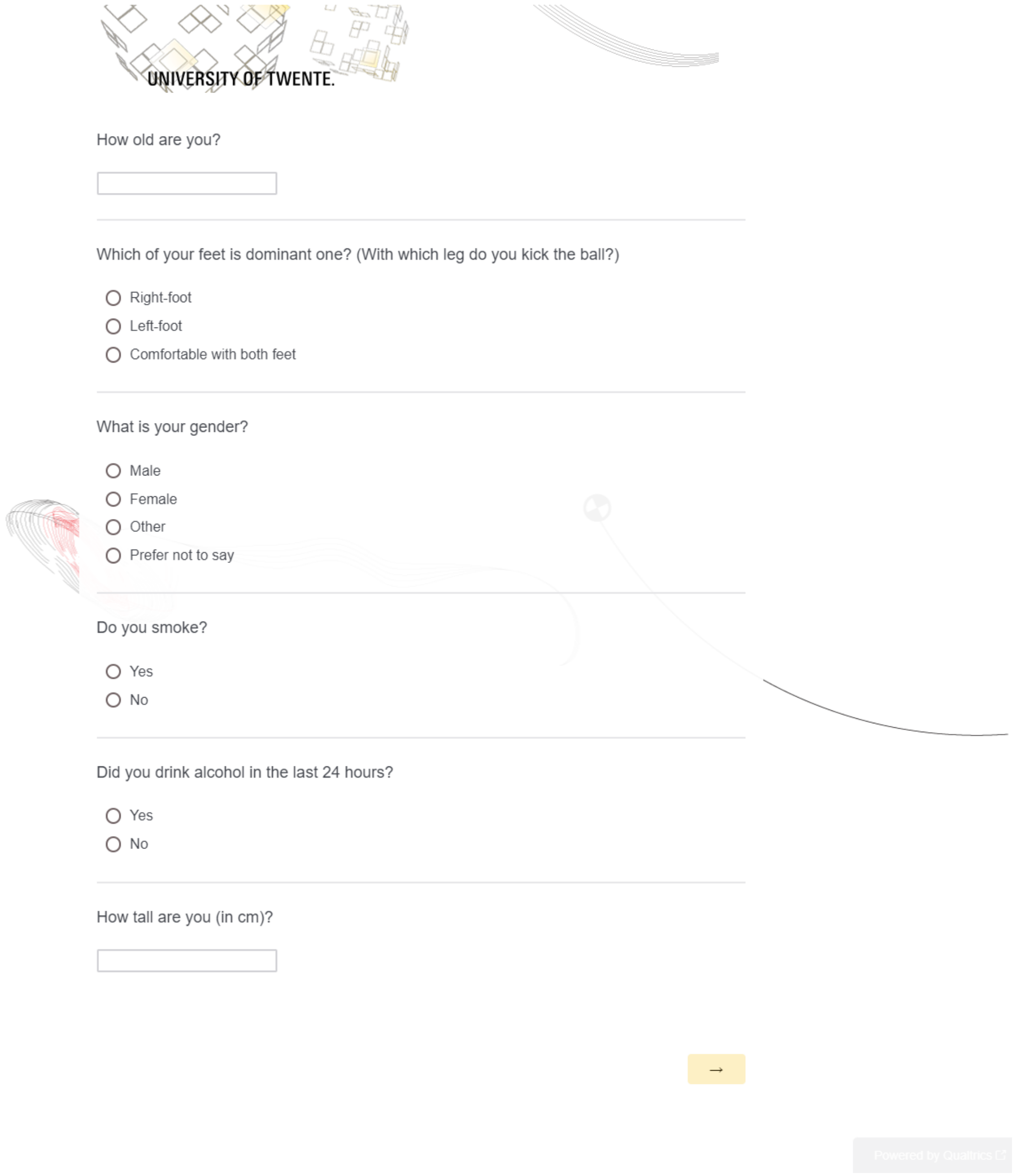
Appendix B

Podcast for Control Group

https://hiddenbrain.org/podcast/you-2-0-decide-already/

Appendix C

Questionnaire



How old are you?

Which of your feet is dominant one? (With which leg do you kick the ball?)

- ○ Right-foot
- ○ Left-foot
- ○ Comfortable with both feet

What is your gender?

- ○ Male
- ○ Female
- ○ Other
- ○ Prefer not to say

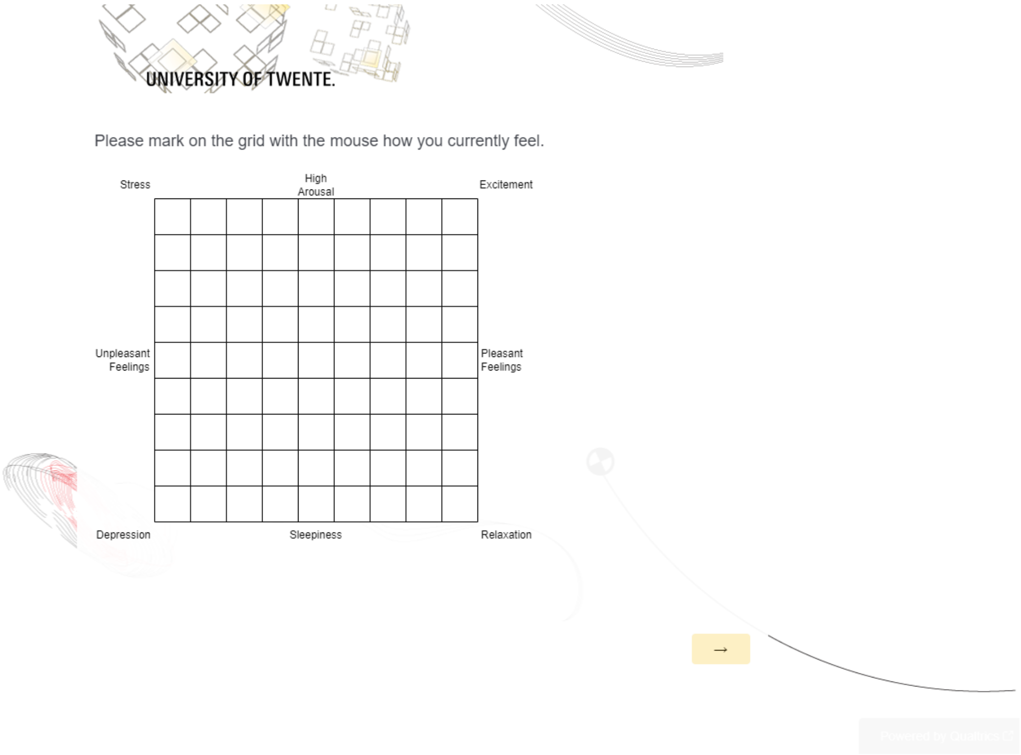
Do you smoke?

- ○ Yes
- ○ No

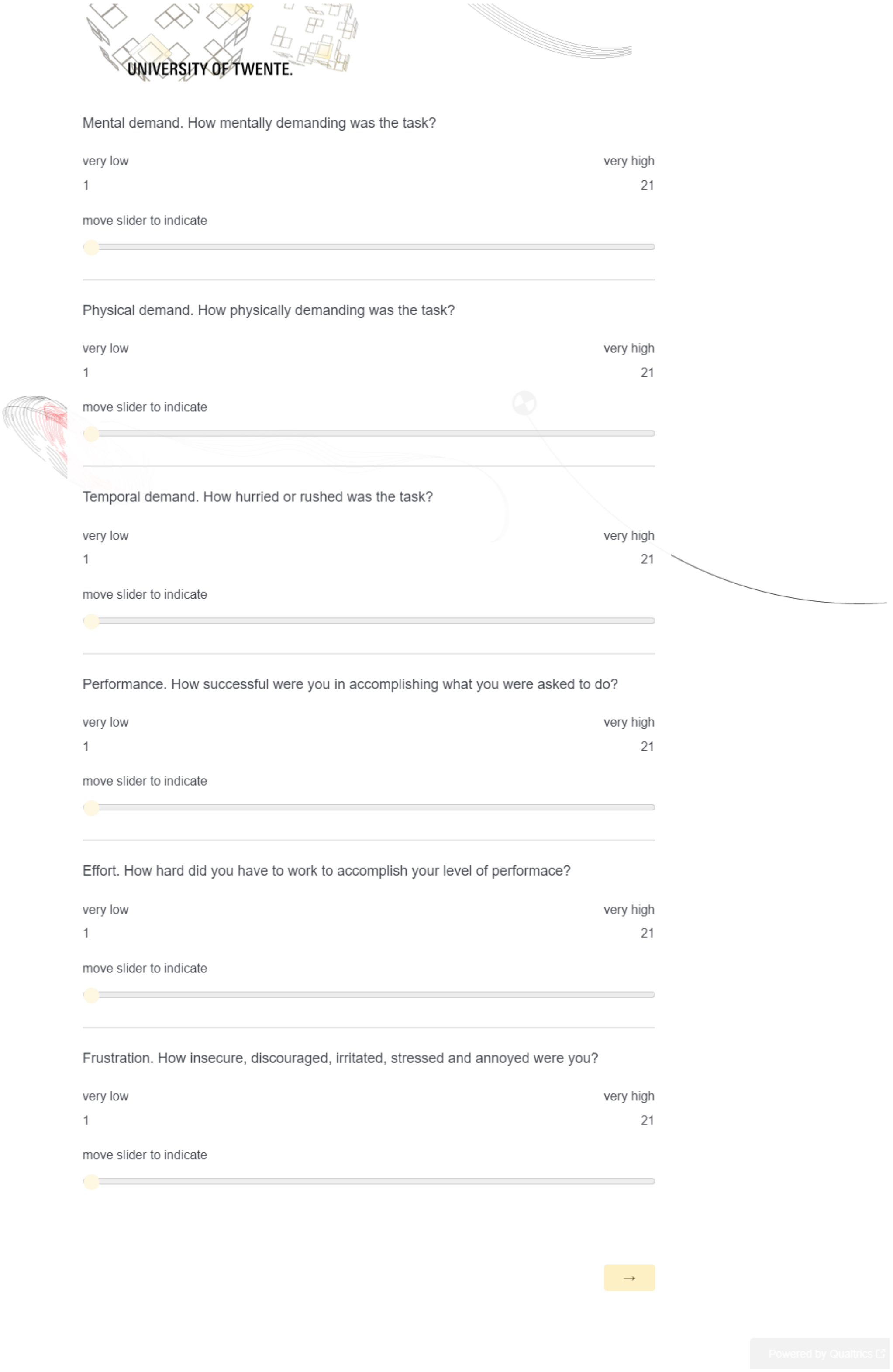
Did you drink alcohol in the last 24 hours?

- ○ Yes
- ○ No

How tall are you (in cm)?



Please mark on the grid with the mouse how you currently feel.



Mental demand. How mentally demanding was the task?

very low 1 — very high 21

move slider to indicate

Physical demand. How physically demanding was the task?

very low 1 — very high 21

move slider to indicate

Temporal demand. How hurried or rushed was the task?

very low 1 — very high 21

move slider to indicate

Performance. How successful were you in accomplishing what you were asked to do?

very low 1 — very high 21

move slider to indicate

Effort. How hard did you have to work to accomplish your level of performace?

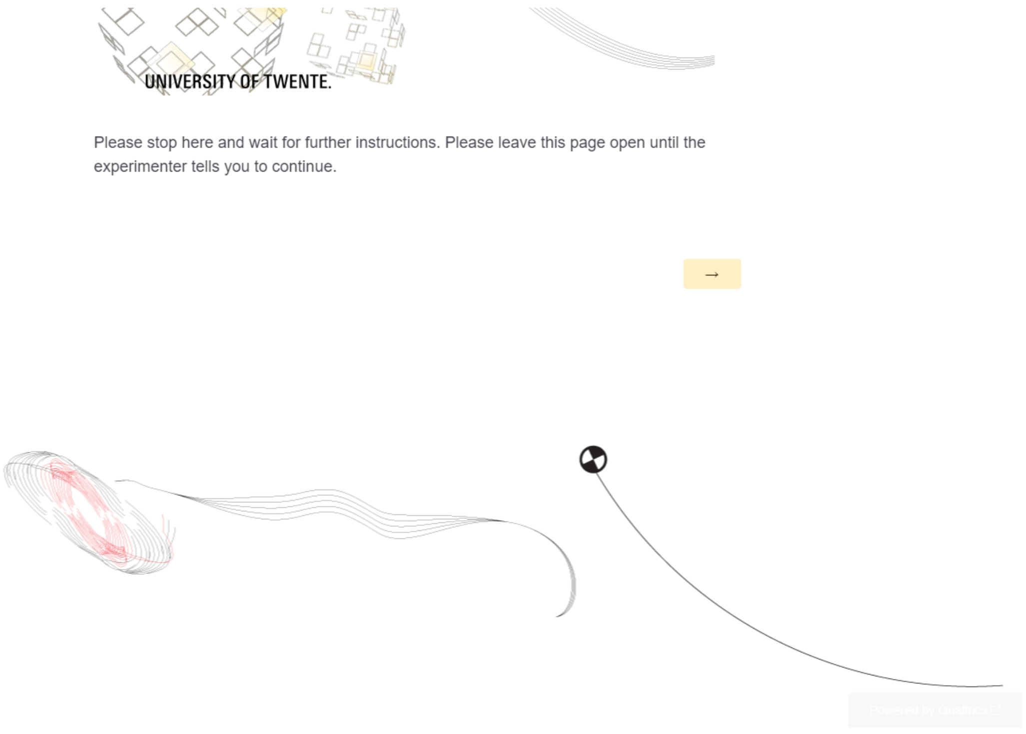
very low 1 — very high 21

move slider to indicate

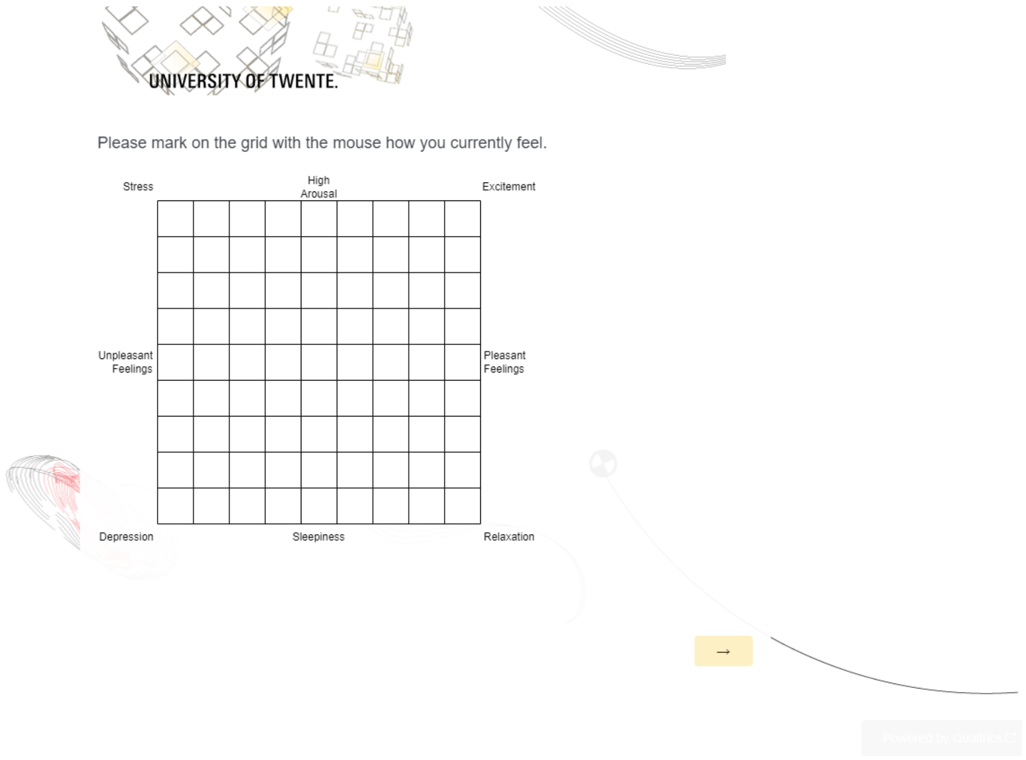
Frustration. How insecure, discouraged, irritated, stressed and annoyed were you?

very low 1 — very high 21

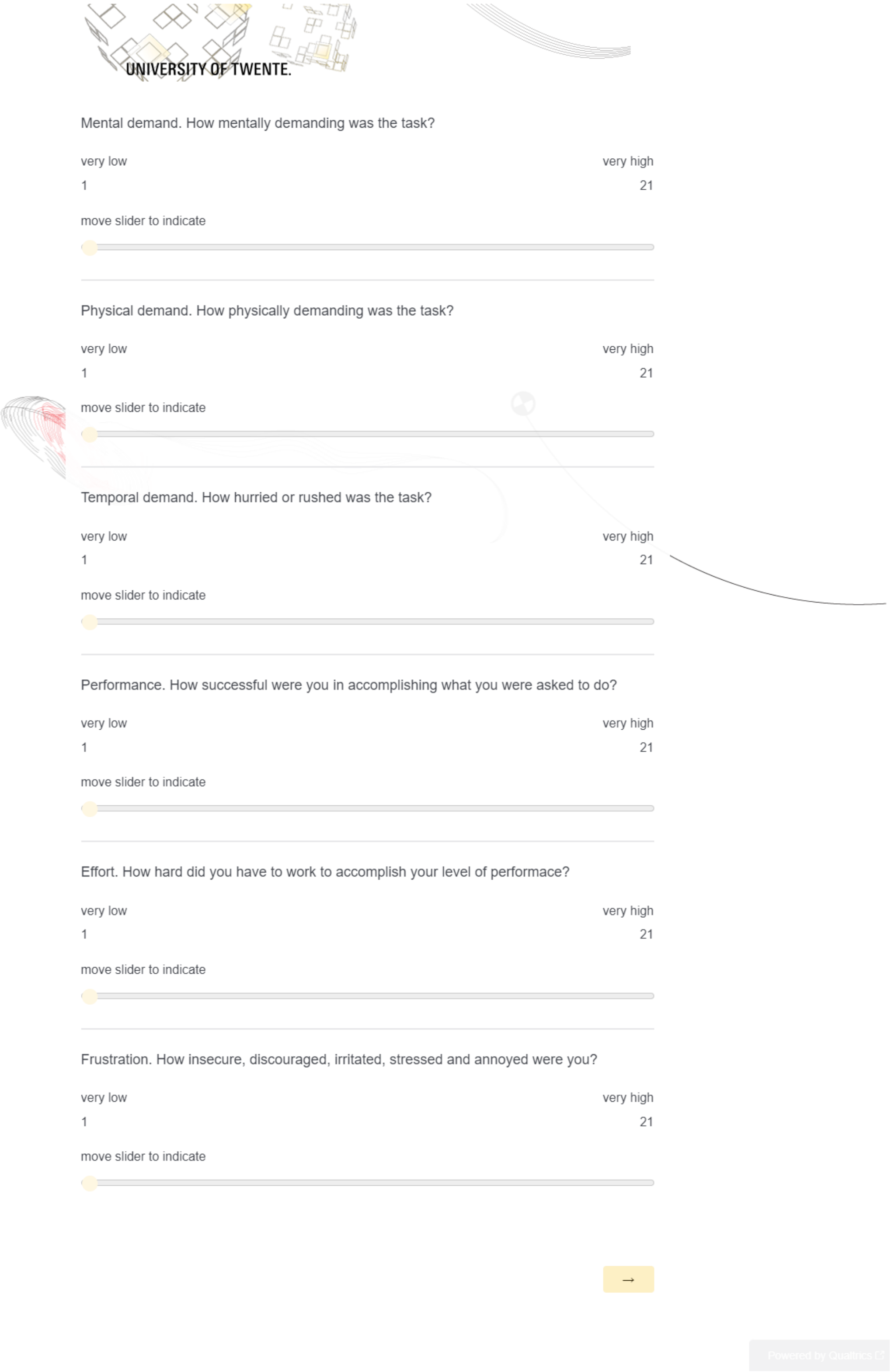
move slider to indicate



Please stop here and wait for further instructions. Please leave this page open until the experimenter tells you to continue.



Please mark on the grid with the mouse how you currently feel.



Mental demand. How mentally demanding was the task?

very low 1 very high 21

move slider to indicate

Physical demand. How physically demanding was the task?

very low 1 very high 21

move slider to indicate

Temporal demand. How hurried or rushed was the task?

very low 1 very high 21

move slider to indicate

Performance. How successful were you in accomplishing what you were asked to do?

very low 1 very high 21

move slider to indicate

Effort. How hard did you have to work to accomplish your level of performace?

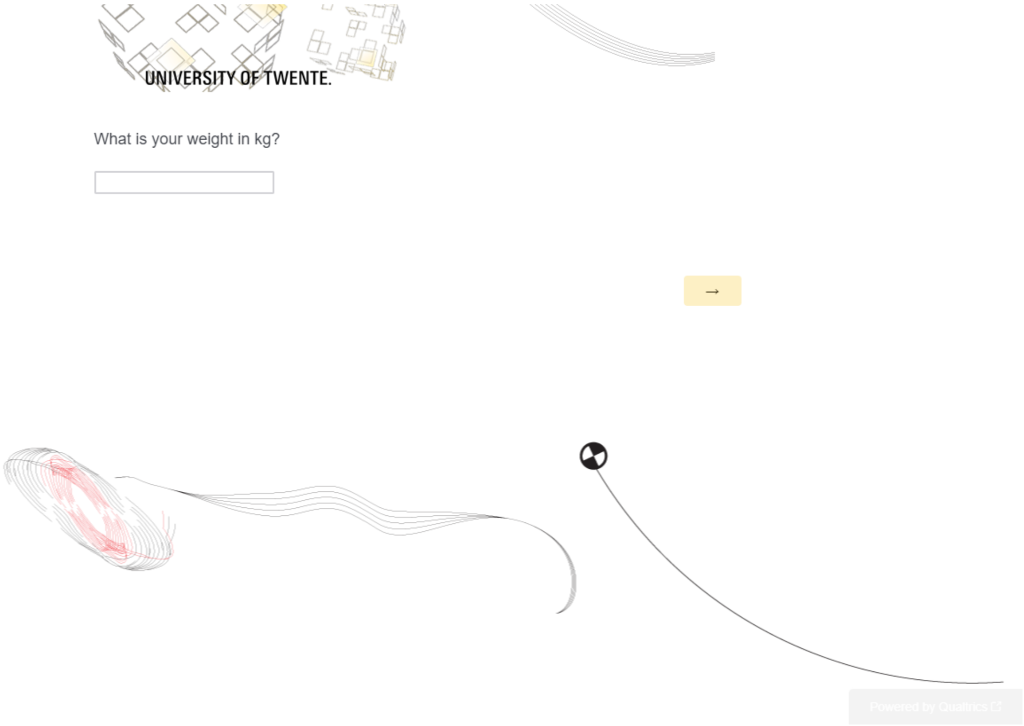
very low 1 very high 21

move slider to indicate

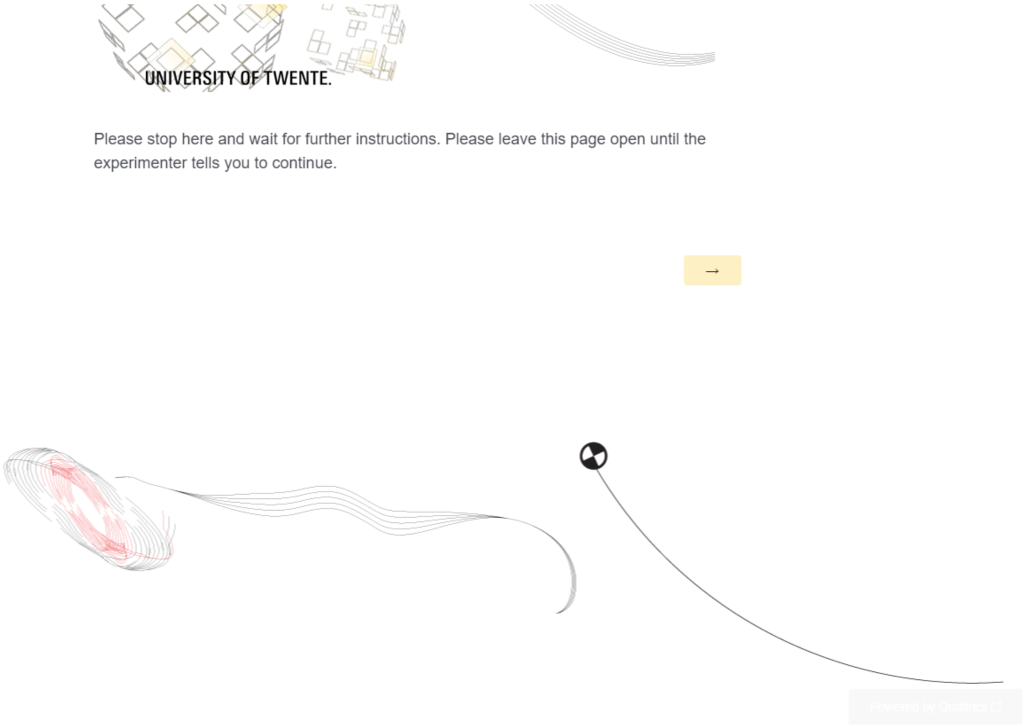
Frustration. How insecure, discouraged, irritated, stressed and annoyed were you?

very low 1 very high 21

move slider to indicate



What is your weight in kg?



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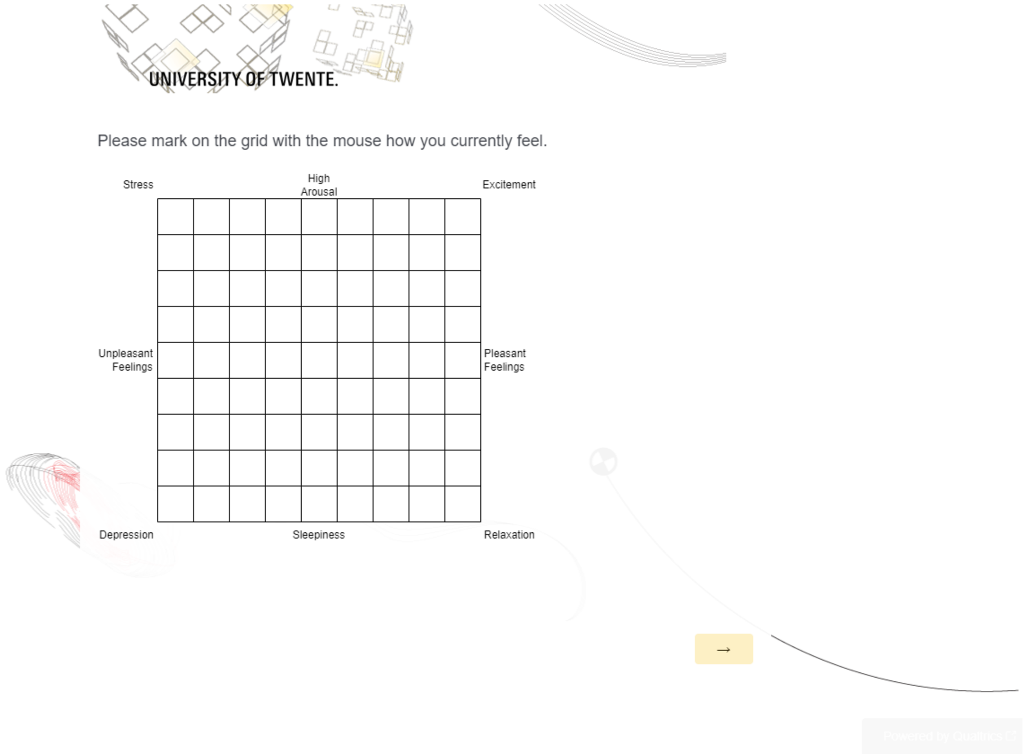
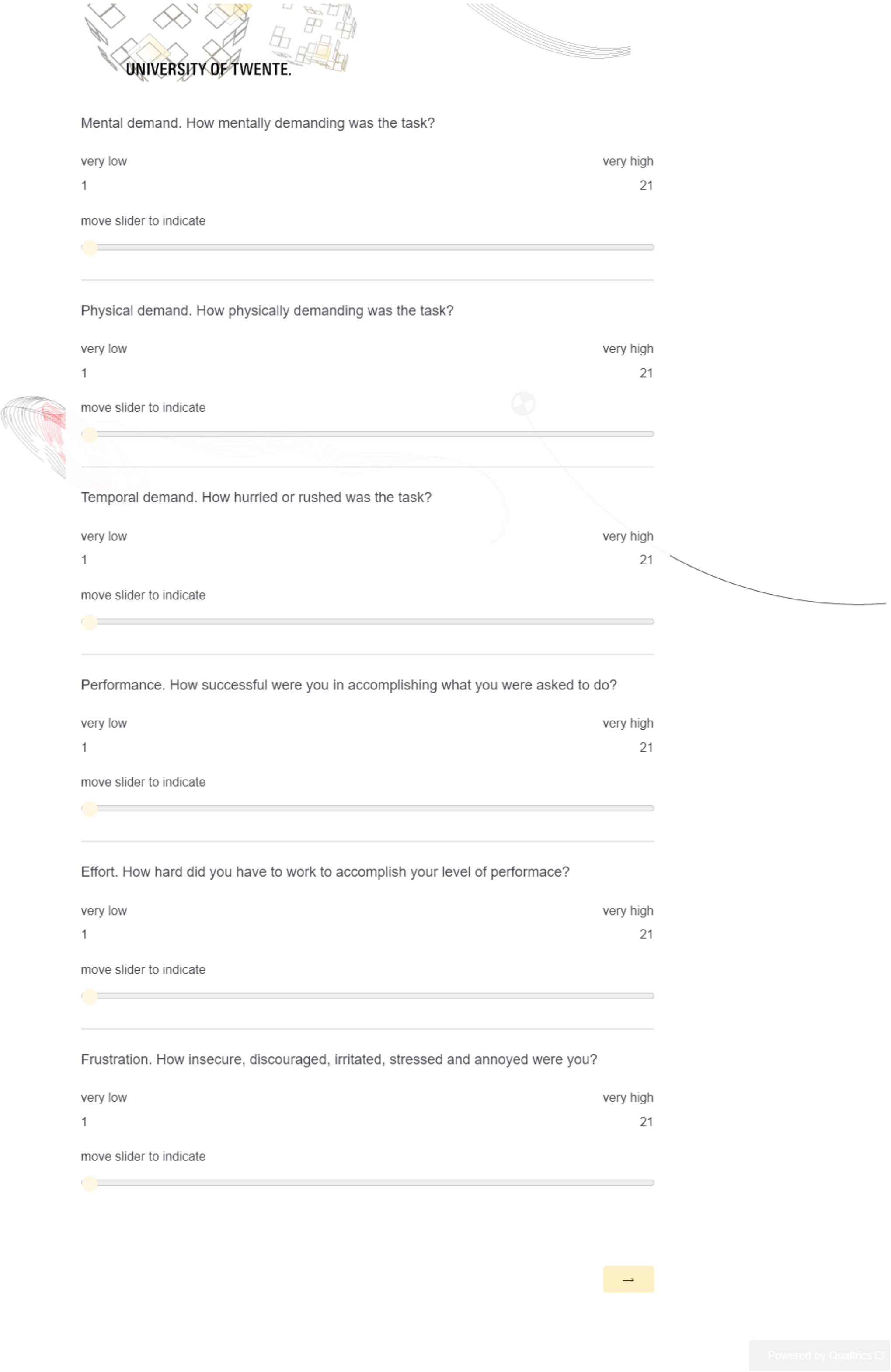


Please mark on the grid with the mouse how you currently feel.



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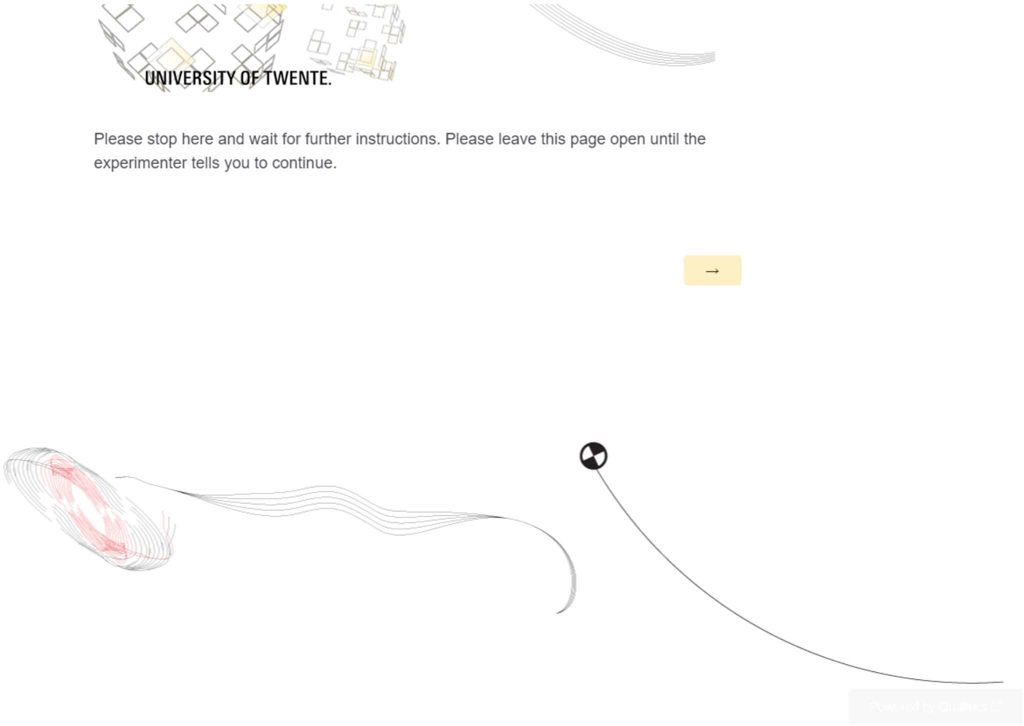
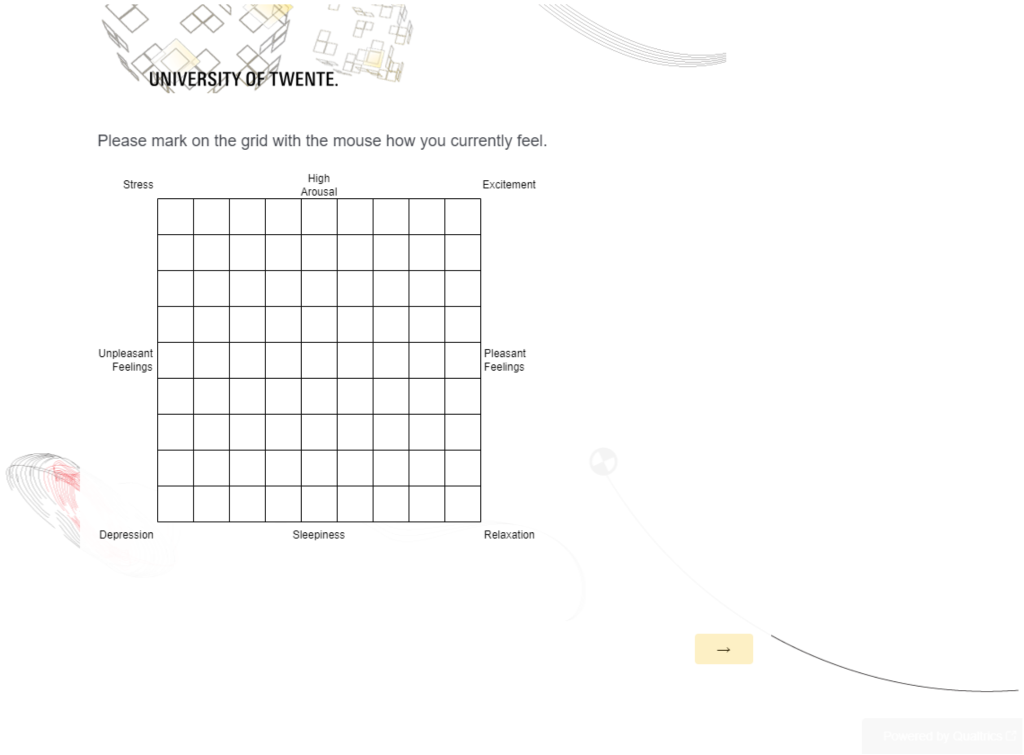
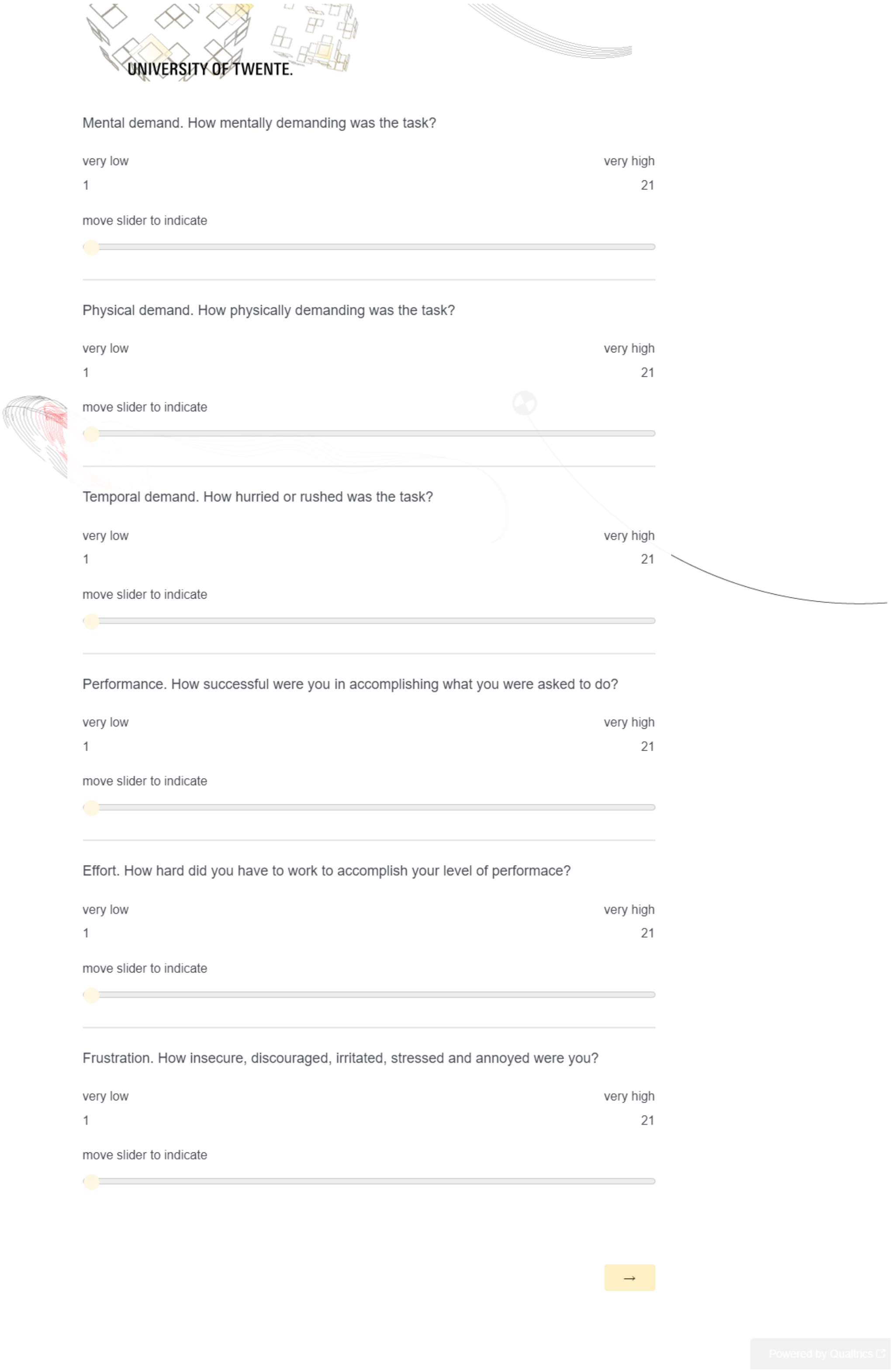


Please stop here and wait for further instructions. Please leave this page open until the experimenter tells you to continue.



Please mark on the grid with the mouse how you currently feel.



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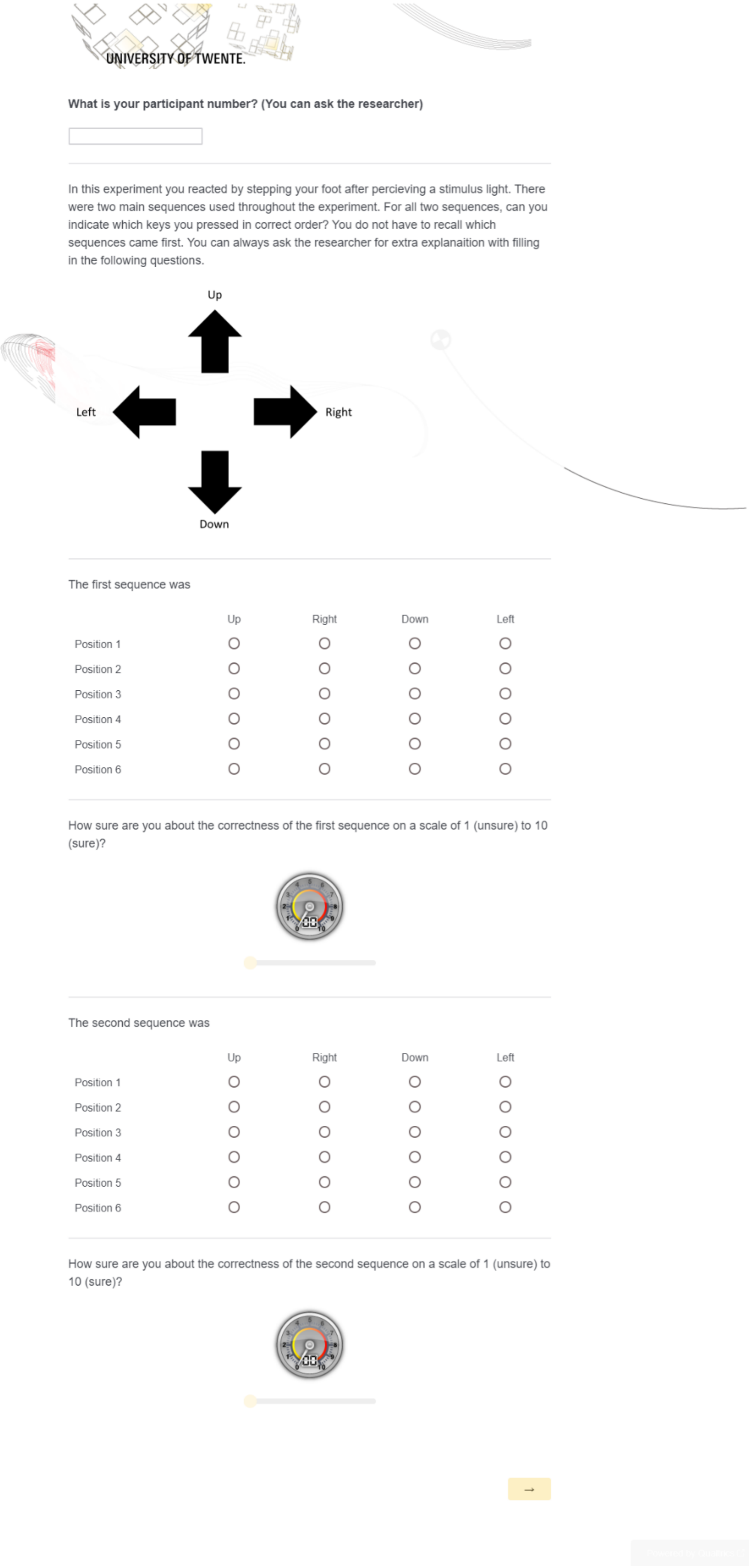


What is your participant number? (You can ask the researcher)

In this experiment you reacted by stepping your foot after percieving a stimulus light. There were two main sequences used throughout the experiment. For all two sequences, can you indicate which keys you pressed in correct order? You do not have to recall which sequences came first. You can always ask the researcher for extra explanaition with filling in the following questions.

The first sequence was

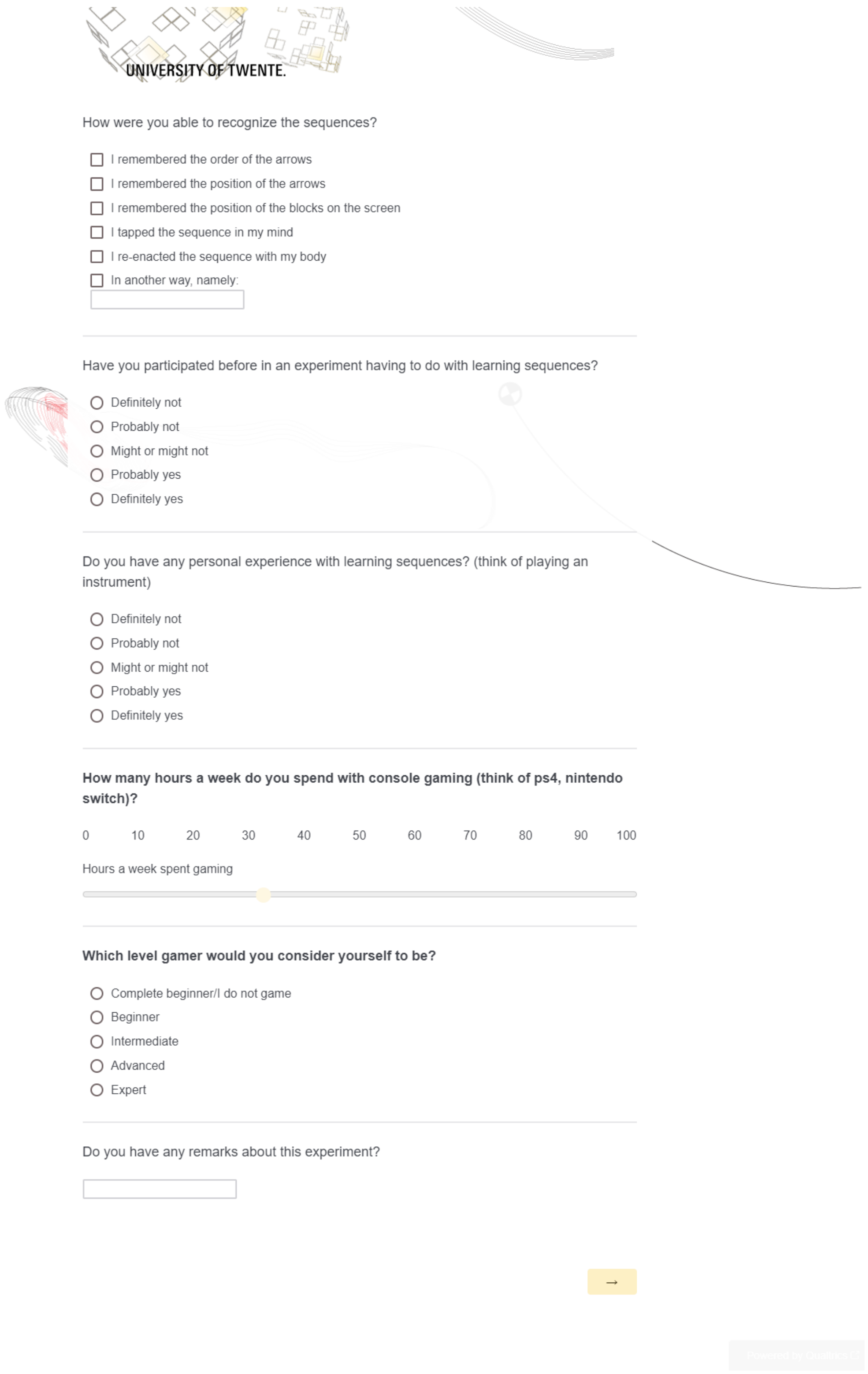
	Up	Right	Down	Left
Position 1	○	○	○	○
Position 2	○	○	○	○
Position 3	○	○	○	○
Position 4	○	○	○	○
Position 5	○	○	○	○
Position 6	○	○	○	○

How sure are you about the correctness of the first sequence on a scale of 1 (unsure) to 10 (sure)?

The second sequence was

	Up	Right	Down	Left
Position 1	○	○	○	○
Position 2	○	○	○	○
Position 3	○	○	○	○
Position 4	○	○	○	○
Position 5	○	○	○	○
Position 6	○	○	○	○

How sure are you about the correctness of the second sequence on a scale of 1 (unsure) to 10 (sure)?



How were you able to recognize the sequences?

☐ I remembered the order of the arrows
☐ I remembered the position of the arrows
☐ I remembered the position of the blocks on the screen
☐ I tapped the sequence in my mind
☐ I re-enacted the sequence with my body
☐ In another way, namely:

Have you participated before in an experiment having to do with learning sequences?

○ Definitely not
○ Probably not
○ Might or might not
○ Probably yes
○ Definitely yes

Do you have any personal experience with learning sequences? (think of playing an instrument)

○ Definitely not
○ Probably not
○ Might or might not
○ Probably yes
○ Definitely yes

How many hours a week do you spend with console gaming (think of ps4, nintendo switch)?

0 10 20 30 40 50 60 70 80 90 100

Hours a week spent gaming

Which level gamer would you consider yourself to be?

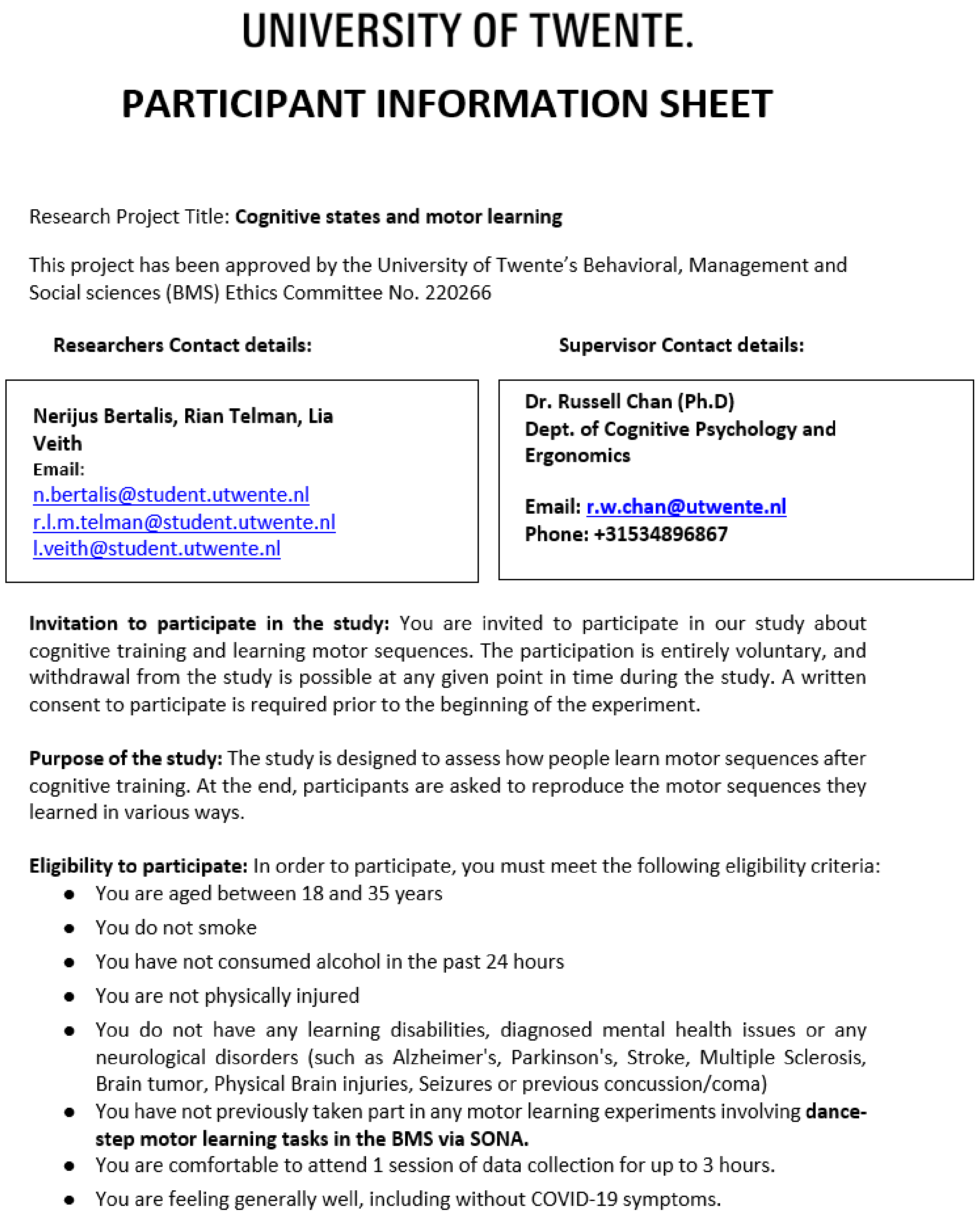
○ Complete beginner/I do not game
○ Beginner
○ Intermediate
○ Advanced
○ Expert

Do you have any remarks about this experiment?

We thank you for your time spent taking this survey.
Your response has been recorded.

Appendix D

Informed Consent



UNIVERSITY OF TWENTE.

PARTICIPANT INFORMATION SHEET

Research Project Title: **Cognitive states and motor learning**

This project has been approved by the University of Twente's Behavioral, Management and Social sciences (BMS) Ethics Committee No. 220266

Researchers Contact details:	**Supervisor Contact details:**
Nerijus Bertalis, Rian Telman, Lia Veith **Email:** n.bertalis@student.utwente.nl r.l.m.telman@student.utwente.nl l.veith@student.utwente.nl	**Dr. Russell Chan (Ph.D)** **Dept. of Cognitive Psychology and Ergonomics** **Email: r.w.chan@utwente.nl** **Phone: +31534896867**

Invitation to participate in the study: You are invited to participate in our study about cognitive training and learning motor sequences. The participation is entirely voluntary, and withdrawal from the study is possible at any given point in time during the study. A written consent to participate is required prior to the beginning of the experiment.

Purpose of the study: The study is designed to assess how people learn motor sequences after cognitive training. At the end, participants are asked to reproduce the motor sequences they learned in various ways.

Eligibility to participate: In order to participate, you must meet the following eligibility criteria:

- You are aged between 18 and 35 years
- You do not smoke
- You have not consumed alcohol in the past 24 hours
- You are not physically injured
- You do not have any learning disabilities, diagnosed mental health issues or any neurological disorders (such as Alzheimer's, Parkinson's, Stroke, Multiple Sclerosis, Brain tumor, Physical Brain injuries, Seizures or previous concussion/coma)
- You have not previously taken part in any motor learning experiments involving **dance-step motor learning tasks in the BMS via SONA.**
- You are comfortable to attend 1 session of data collection for up to 3 hours.
- You are feeling generally well, including without COVID-19 symptoms.

Participants will be assessed on eligibility by a researcher, prior to the start of the experiment.

Requirements:

Participation in the research study involves attending a laboratory session ONCE for up to 3-hours.

Lab Session (~3 hour):

During the beginning of the session, the participant demographics (age, gender, education,…) will be captured. Your information will be anonymised immediately following data collection completion. You will be asked a self-report questionnaire before the experiment begins.

Firstly, you will be required to sit and quietly perform a listening task with your eyes closed for approximately ~25 minutes. You will then again be asked the same self-report questionnaire.

Next, participants will then be introduced and demonstrated a learning task that requires them to use their feet to respond. Participants are required to perform 6 blocks in which they learn 2 motor sequences. At the half point within each block, participants are given a 30 second break in which they stay in position but can stretch, for example. At the end point of each block, participants will have a 3-minute break in which they may be seated and can bring something with them to read. After learning blocks, participants then proceed to proceed with the test block

After the longer break, participants will start with 2 blocks of sequence testing. Again, participants will have a 3 minute break at the end point of each block and a 30-second break at the half point of each block. At the timepoint of the last 3-minute break, participants will be given two types of explicit testing for their sequence knowledge.

Finally, participants will be debriefed about the goal of the experiment and will be informed about the use of the data and they will be thanked for their participation. This will conclude the session.

Risks and benefits: This study does NOT include aspects which may be considered harmful or dangerous, compared to regular daily activities.

Reporting and maintenance of data and participant information: All data regarding personal information (i.e. name, age, gender, etc.), or otherwise usable for identification, will be kept under confidentiality at all times, unless required to otherwise by law. Additionally, participant data will be handled under identification numbers, ensuring further anonymity.

Furthermore, no data concerning your personal information will be discussed during result conversations. The collected data associated to your session will be stored for a minimum of 5 years and a maximum of 10 years.

Summary report of this study's findings: After publication, a copy of the study's abstract will be distributed to participants via E-Mail if you have indicated interest.

Consent Form for: Cognitive states and motor learning

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [__________________] (DD/MM/YYYY). I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I fully consent with taking part in the study and understand that I can refuse to respond or withdraw from the study entirely without consequences.	○	○
I understand that taking part in the study involves one laboratory session and data recording is performed on the computer.	○	○
Use of the information in the study		
I understand that information I provide will be used for publication, conference presentation and scientific reports.	○	○
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will be de-identified and not be shared beyond the research team.	○	○
Future use and reuse of the information by others		
I give permission for the *data* that I provide to be archived in BMS Datavault and made anonymous so it can be used for future research and learning.	○	○
I agree that my information may be shared with other researchers for future research studies that may be similar to this study or may be completely different. The information shared with other researchers will not include any information that can directly identify me. Researchers will not contact me for additional permission to use this information.	○	○
I give the researchers permission to keep my contact information and to contact me for future research projects.	○	○

Signatures

Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Russell Chan		
Researcher name	Signature	Date

Study contact details for further information: Dr. Russell Chan, r.w.chan@utwente.nl

Appendix E

Link to R Code

https://rpubs.com/lukasberndt/1056577