UNIVERSITY OF TWENTE.

Mental Training For Cognitive Enhancement In Motor Learning

Bachelor Thesis

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The data collection of the data which this thesis is based on has been collected in collaboration with two other BSc thesis students, namely Rian Telman and Lia Veith.

Abstract

The ability to learn and remember what was learned is fundamental for people to live well. Motor sequence learning (MSL) is a phenomenon in which actions become optimised to support the daily living processes involving motor sequences. Previous work suggested that cognitive control functions play a crucial role in the ability to successfully engage and excel in MSL. The cognitive control functions may be enhanced through a cognitive task, such as Open Monitoring Meditation (OMM), which is executed prior to MSL. It is anticipated that the OMM induces creative problem solving which may be beneficial during the MSL process. The Discrete sequence production (DSP) paradigm, which uses high amounts of key-presses sequence practice, is often used to investigate the MSL. Most motor sequences people engage in involve the whole body, thus, a more pragmatic approach to investigate the MSL could be to modify the key-press version of DSP to involve full body movements. The present study aimed to investigate whether the OMM condition enhances MSL performance in participants during the dance-step DSP task. A total of 24 participants took part which were split into two equal groups of control and OMM conditions. Participants executed 8 sessions of 2 different sequences over 48 trials each. The parameters of interest were Response Time (RT) and Accuracy. The results showed that the OMM group performs faster than the control group during MSL. Furthermore, it was found that the OMM condition was engaging in the chunking mode in the last sessions. Chunking behaviour in the control group was not observed.

Keywords: Discrete Sequence Production, Open Monitoring Meditation, Cognitive enhancement, Motor Sequence Learning, Cognitive control.

1.0 Introduction

Motor sequence learning (MSL) is a goal-directed behaviour which influences how we learn and execute daily tasks. Sequential tasks such as driving a car, playing a sport, operating machinery and playing an instrument all depend on how well we learn and acquire sequences. According to Abrahamse et al. (2013), MSL is focused on optimizing the performance of sequences in a manner that the accuracy and speed are the most optimal.

A prominent way to investigate MSL is grounded in the research with the Discrete Sequence Production (DSP) task proposed by Verwey (1999). According to Rhodes et al. (2004), the DSP paradigm consists of motor sequences that are simple for the participants (consisting of key presses) and allow distinction between cognitive mechanism and movement implementation itself. Being able to investigate how people perform in MSL motivated researchers to look for ways how the learning could be enhanced.

MSL is a goal-directed behaviour that relies on cognitive functions such as attention memory and cognitive control interactions for successful MSL performance (Chan et al., 2018). If sequence learning is expected to be influenced by cognitive control, then it would be reasonable to expect that cognitive tasks like meditation can establish distinct control states that in turn influence MSL (Chan et al., 2018). Specifically, the current thesis is interested in Open Monitoring Meditation (OMM) during which the participant is motivated to focus on general present moment awareness including bodily sensations (Lutz et al., 2008). A single session of OMM is believed to enhance cognitive flexibility and creativity regarding problem-solving (Colzato et al., 2015; Colzato et al., 2016). The enhanced creativity may result in participants looking for creative solutions to improve their sequence execution. Furthermore, according to Lippelt et al. (2014) and Lutz et al. (2008), meditation has a significant influence on cognitive processes like perception, information processing, attention and emotion which are important cognitive functions in MSL.

The present study will further investigate the possible impact of OMM cognitive enhancement on MSL. Furthermore, the DSP paradigm will be tested with a dance-step task instead of the traditional key-press version during the MSL.

1.1 Discrete Sequence production:

Discrete Sequence Production (DSP) is an MSL paradigm developed by Verwey (1999). The paradigm consists of elements that require a small amount of time to react and involves high amounts of training. The reason to implement rapid and effortless movements arises based on the assumption that the RT illustrates the underlying cognitive processes which could be undetectable throughout other consecutive bodily movements (Rhodes et al., 2004). The DSP task requires participants to map down their fingers to fixed response locations on the appointed keys on the keyboard. From four to eight fingers are mapped and an identical number of placeholders are displayed in accordance with the keys. Each placeholder resembles a key in a dimensionally analogic manner. When the placeholder lights up the participant has to react as fast as possible to the stimuli and press the key which resembles the lit-up placeholder. Afterwards, another stimulus is shown. The aforementioned design continues and participants become faster and more efficient as they go through different learning phases (Abrahamse et al., 2013).

1.2 Cognitive Framework for Sequential Motor Behaviour

Cognitive control is a crucial component of MSL as it regulates attention allocation, working memory and additional executive functions like response choice and task description that are used to enhance performance during the sequence execution (Daltrozzo & Conway 2014; Keele et al., 2003; Slagter et al., 2011). The cognitive control process describes several information management approaches, including attention narrowing and attention tampering inhibition, that are used to support successful goal-related behaviour (Miyake et al., 2000; Gratton et al., 2018).

Since cognitive control processes play an important role in sequential task execution, the Cognitive Framework for Sequential Motor Behaviour (C-SMB) paradigm was proposed to explain the underlying cognitive information processing architecture of sequential motor tasks (Verwey et al., 2015). The framework emphasises that processors exist at three distinct stages. Firstly, in case the stimulus is presented to the participant, its characteristics are treated by the perceptual processor and uploaded to the short-term memory where the information is being utilised by the central processor. Secondly, the central processor acts as a junction between perceptual and motor processors. The central processor converts the perceptual processor input and sends it to the motor processor. Lastly, when the motor processor receives the information, it starts to execute it (Shaffer, 1991).

Performance during the DSP task sequence execution involves three execution modes (Verwey & Abrahamse, 2012). The first is called reaction mode during which participants utilise every key-particular stimulus to choose a response. This mode is mainly used when participants are exposed to unfamiliar sequences. During this stage, participants react to a stimulus which is recorded by the perceptual processor which conveys the information to short-term memory. From there, the central processor uploads the information to the motor buffer from where the information flows toward motor processors (Verwey et al., 2015). At this stage, the movement is produced. With unfamiliar sequences for which no sequence knowledge is built yet, this cycle continues until the stage of associative mode is reached.

The second is called associative mode and is observed when after continued practice the participant began to establish associations between successful stimuli at motor, cognitive and/or perceptual stages. During the associative mode, associations between correct responses are used by the participant to execute the task faster (Verwey & Abrahamse, 2012).

After continued practice with the sequence, participants become familiar with the sequence order and start to execute it in a chunked manner (Verwey & Abrahamse, 2012). This phenomenon is called chunking mode. During this mode, the central processor is mainly responsible for the loading of the first stimuli and transferring information to the motor buffer. Afterwards, the sequence is executed as it would represent a single response which allows participants to reach fast RTs.

There are three phases that are believed to represent a rightly learned keying sequence as seen in Figure 1 (Abrahamse et al., 2013). The first stage is indicated as sequence initiation and it refers to the first reaction/first key press. Referring to the DSP paradigm, the initiation phase would include sequence selection and preparation of loading into the motor buffer (Verwey, 1999). The second stage is referred to as the execution phase which is distinct by its relatively short RT performance. The shorter RT is possible since this stage is involving only execution and initiation/preparation was already done in the previous stage. The last stage is called the concatenation phase and it refers to the changeover time point between motor chunks and is distinctive by its longer RT. During this stage, the longer RT is thought to be due to higher cognitive demand because of a new motor chunk being loaded (Abrahamse et al., 2013).

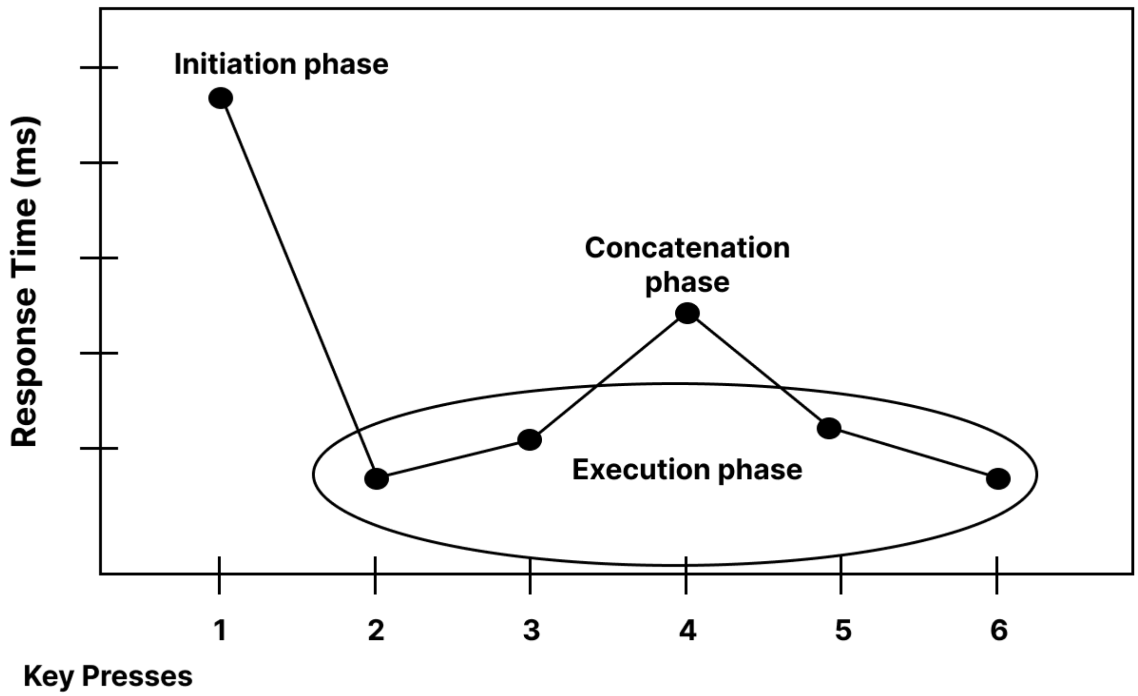


Figure 1. A typical sequence execution with 6 key presses. The three stages are visualised that represent a well-learned sequence. The slow initial start represents the loading of the first stimuli and identifying the chunk from the memory. It follows by a fast execution phase and concatenation point which loads another chunk. The slower RTs values within the concatenation point refer to cognitive processes involved in loading the following chunk. Adapted from "Control of automated behavior: insights from the discrete sequence production task" by E. L. Abrahamse et al. (2013). *Frontiers in Human Neuroscience*, 7.

1.3 Recent step-based MSL research

Recent work has transformed the finger-based MSL into a task that may represent the daily MSL process better since the whole body is involved. In a study by Du and Clark (2018), a dance-step motor task rather than a finger-based task was incorporated into motor task execution. There are multiple reasons outlined by Du and Clark (2018), why the whole-body motor task was preferred instead of the traditional finger press task. One of the more important reasons is that the full-body sequence task allows for a more accurate display of the daily sequential tasks people perform on daily basis (Du & Clark, 2018). Furthermore, Wiechmann (2021) has investigated whether key-press DSP task yields similar results to dance-step DSP during MSL. Results showed that the dance-step DSP provides comparable results to the key-press DSP (Wiechmann, 2021).

1.4 Cognitive enhancement

According to Hommel and Colzato (2017), meditation has an instantaneous effect on the cognitive control states and different meditation conditions differ in their effects. A model to explain how meditation can have an effect on cognitive control was proposed by Malinowski (2013). The model is called the Liverpool Mindfulness model which is divided into different layers (see Figure 2). The first layer refers to motivational factors, the second to mind training, and the third to core processes (Malinowski, 2013). To provide an example of how the Liverpool Mindfulness model works in practice let's envision a fictional person who is influenced by motivation factors like expectations and intentions (first layer) and starts to practice mindfulness (second layer). As follows, the core processes are refined after regular engagement in mindfulness exercise (third layer). The core processes refer to functions which are also important for MSL, for example, attentional control and cognitive flexibility (Malinowski, 2013; Amer et al., 2016). According to Malinowski (2013), people who engage in mindfulness meditation benefit from enhanced attentional functions like attentional control and sustained attention. In support, Schmertz et al. (2008) discovered that participants who indicated higher self-reported mindfulness scored better results in a task commonly used to assess sustained attention

(Continuous performance test). Furthermore, it was found that participants who self-reported higher in mindfulness and meditation training exhibited higher performance results during the Stroop task (Chan & Woollcott 2007; Teper & Inslicht 2013; Moore & Malinowski 2009). The findings are valuable since the Stroop task requires high attentional control as participants have to react to conflicting stimuli and identify the correct one. For example, the word "Blue" is presented in a red colour and participants have to indicate the font colour of red (Stroop, 1935). A good performance in the Stroop task is associated with low levels of impulsivity, automaticity and high levels of attentional management which are important functions in cognitive control during MSL (Malinowski, 2013; Daltrozzo & Conway 2014; Keele et al., 2003; Slagter et al., 2011).

A number of overlapping cognitive control properties can be observed between meditation and MSL. For instance, Daltrozzo and Conway (2014), Keele et al. (2003) and Slagter et al. (2011) emphasised that cognitive control, sustained attention and cognitive flexibility influence the MSL task performance. Furthermore, Schmertz et al. (2008), Chan and Woollcott, (2007), Teper and Inslicht (2013) and Moore and Malinowski (2009) argued that engaging in mindfulness practice, attentional control, and sustained attention could be enhanced. Based on the aforementioned, one can notice that the cognitive functions the mindfulness practice enhances are similar to functions that are needed for a good MSL performance. Thus, it is likely to expect that individuals who engage in the meditation practice benefit from enhanced MSL performance.

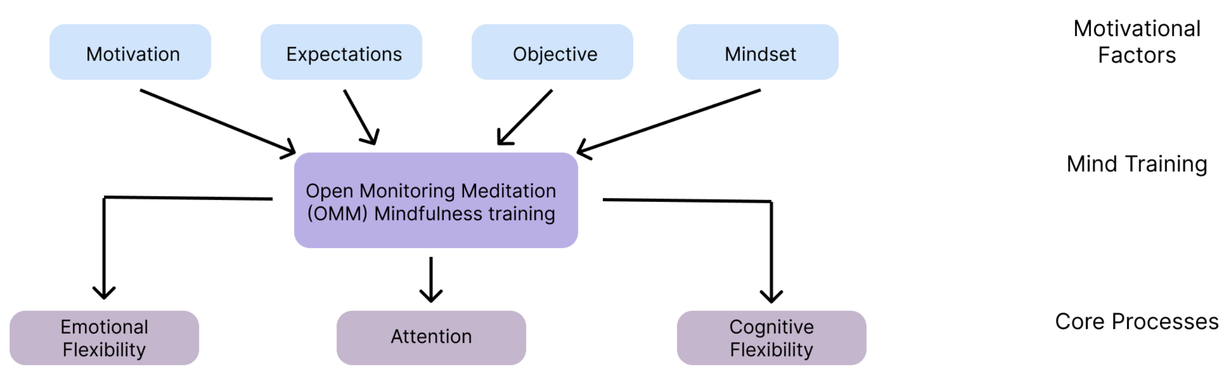


Figure 2. Mindfulness model. The layers are indicated on the right side. The first one is Motivational factors and it resembles motives to engage in meditation. The second layer is Mind training and it refers to the meditation itself. The third level of Core processes refers to the improvement of cognitive functioning of processes like attention and cognitive flexibility. After receiving the OMM training, participants should be cognitively enhanced and be able to integrate information from different sources. Adapted from P. Malinowski, (2013). Neural mechanisms of attentional control in mindfulness meditation. *Frontiers in neuroscience*, 7, 8.

1.5 Effects of a single session of OMM on MSL

According to Hommel and Colzato (2017), a single OMM session is believed to be enough to influence the cognitive control forms. The OMM condition is believed to induce states of weakened top-down cognitive information processing, which allows participants to engage in a more flexible learning process regarding MSL (Colzato et al., 2016). The support for weakened top-down processing after a single session of OMM was observed in a study by Colzato et al. (2016), whereas the ability to suppress task unrelated information was weaker in the OMM condition compared to other meditation groups. Furthermore, the weakened top-down processing allows participants to engage in more creative and flexible problem-solving (Amer et al., 2016).

The study by Immink et al. (2017) showed that participants after receiving the OMM condition showed an increase in MSL RT performance compared to the control group (Immink et al., 2017). Additionally, the study showed that the OMM condition displayed higher sequence-specific knowledge when compared to the control group. However, the results were significant only with participants who indicated low effort for meditation. This may suggest that the effort part which was not used in meditation could have been used in MSL and thus participants reached faster RTs. Furthermore, participants showed higher levels of disturbance and error when the relatively known sequence was alternated (Immink et al., 2017).

A different approach to reaching mental enhancement is through engagement in Focused Attention Meditation (FAM). Previous research by Chan et al. (2017) has investigated FAM effects on MSL. An important distinction between FAM and OMM is that in the FAM condition, the goal is to narrow down the selective attention on specific chosen aspects such as breathing or surrounding sounds (Lutz et al., 2008; Vago & Silbersweig, 2012). During the OMM the goal is to focus on more bottom-up driven awareness of sensations without judgement rather than one specific item, for example, participants can focus on general presence feelings (Lutz et al., 2008; Vago & Silbersweig, 2012). The results of Chan et al. (2017) showed that there was a significant difference between people who had received FAM 22 minutes prior to their MSL and those who received FAM immediately before engaging in MSL. More precisely, participants who did not receive a break prior to MSL showed higher levels of MRT compared to the meditation group with a break (Chan et al., 2017). It makes sense to reason that immediately after meditation cognitive control functions are weakened and require time to recover. Furthermore, both FAM conditions, with break and without, outperformed the control group in MSL performance (Chan et al., 2017).

1.6 The Present experiment

The current study seeks to investigate the cognitive enhancement functions of MSL by looking at how the OMM condition will influence the participants during MSL. The task will be based on the Dance-step DSP (DS-DSP) paradigm to investigate MSL. The researcher question of the current paper is: What effect does a single session of OMM have on young adults during subsequent learning performance in the DS-DSP task? Three specific hypotheses are formulated:

1. H1: Participating in the OMM condition will result in increased MSL performance compared to a control condition during MSL.
2. H2: Participating in the OMM condition will result in longer RTs with the unfamiliar sequence compared to the control condition during MSL.
3. H3: Participating in the OMM condition will result in a more induced chunking mode compared to the control group during MSL.

2.0 Methods

2.1 Participants

For the present experiment researchers recruited a total of 24 healthy participants between the ages of 18 to 35 years old that were mostly students from the University of Twente and lived within a 25 km radius of the university. The participants were recruited through the University's “Sona system”. The following criteria for participation in the present study were held: 1) The participants have to be in the age range of 18 to 35 years old and have no serious mental or physical health issues which could affect their performance; 2) The participant should have not consumed alcohol in the last 24 hours prior to the experiment; 3) The participant should have not engaged in meditation prior to the experiment; 4) The participants should not have any of the Covid-19 symptoms.

Twenty-four participants took part in the current experiment (15 males and 9 females, mean age 21 ± 2.6, 83% right-footed). The dominant foot was identified by firstly asking the participants and if they were not sure about which foot was the dominant one, they were asked to stand up straight and lightly pushed forwards from the back. Which leg went forwards to stop the fall was marked as a dominant foot. Twelve participants were randomly assigned to the control condition and twelve to the OMM testing condition.

2.2 The DSP task

The present experiment used the DSP task which is translated from traditional keyboard presses to a dance-step mat. The participants had performed the task on ‘Non-slip dance pad version 5’ by D-force (see Figure 1). The participants during the experiment part stood in the middle of the dance pad and were visually directing their attention toward the screen where four sessions positioned in accordance with the dance pad arrows (↑, ↓, → and ←) displayed sequences. The span between the screen and the participant is around 1 meter. The script ran on the computer and the computer was connected to the screen to visualise it for the participants.

Figure 3. The experimental settings. The participant is standing in front of the screen and in the centre of the dance pad. After the sequence is displayed on the screen, the participant has to reproduce it on the dance pad. The sequence contains 6 steps. The participant has to wait until all 6 blocks have been shown on the screen the blue/red cross to lit up before engaging or restraining from sequence execution. Reprinted 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), (Bachelor's thesis, University of Twente).

The E-Prime® software (Version 2.0.10.356) was used to run the stimuli script on the screen. Furthermore, the E-Prime® software was used to gather the parameters of RT and accuracy. The trials participants had received consisted of six steps that were visually presented on the screen by four square blocks which lit up in a sequence-specific manner (see Figure 4). The four blocks presented on the screen were dimensionally representing dance pad arrows on the dance mat (see Figure 3). In the experiment, some sequences were treated as “no go” and accounted for 8% of all sequences. The “no go” condition was presented by the red cross at the end of the shown sequence. On the contrary, when the cross lit up with the colour blue, it would indicate a “go” condition. The “go” condition represented 92% of all sequences. During the “go” condition, the participants had to reproduce the task on the mat as fast as possible. The stimuli were presented on a 24inch LG Flatron HD screen with a 60Hz refresh rate. A total of 8 sessions were executed by the participant where the first six were training sessions and the last two are testing sessions with familiar and unfamiliar sequences. The last two sessions will be counterbalanced. In other words, the order in which they occur changes per participant. Furthermore, the sequences themselves are counterbalanced between the participants. Two sequences are used in the experiment, sequence 1: ←→↑↓→← and sequence 2: →↑←↑→↓. These sequences were rotated four times which produced eight different sequences. Since the participants received different sequences, the potential variations in the foot strength or sequence toughness are not likely to influence the learning process for the participants. In the experiment, a session consists of 48 sequences and each sequence of six steps. The two sequences were presented 24 times per session and the display of the sequence was randomized. A sequence consisted of six steps. An example of the sequence stimuli can be observed in (see figure 4)

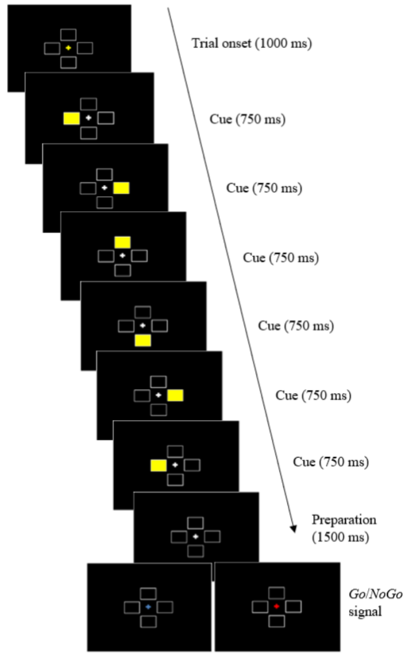


Figure 4. An example of a trial consisting of 6 cues. In the end, participants are faced with a go condition (blue cross) or no go condition (red cross). Reprinted from "The discrete sequence production task in the form of a step task: an application of individual exponential learning curves in motor sequence learning." by E., Wiechmann (2021), (Bachelor's thesis, University of Twente).

2.3 Tests

2.3.1 Affect grid

The Affect Grid was used in the present study to assess the pleasure and arousal of participants. The two dimensions were measured on a 9x9 grid with scores ranging from 1 to 9 whereas 1 indicated low and 9 indicated a high level of dimension (Russell et al., 1989). The values for the affect grid were entered into the quantitative website of "Qualtrics" (see Appendix A). Although these measures were collected, they are not the subject of analysis in this thesis.

2.3.2 NASA TLX

To assess the task's influence on the participant, the NASA Task Load Index (TLX) was used. The questionnaire assesses the six aspects: mental demand, physical demand, temporal demand, performance levels, effort levels and frustration levels (see Appendix B). Although these measures were collected, they are not the subject of analysis in this thesis.

2.4 Procedure

Before the start of the experiment, participants were greeted by the researcher and all necessary documents as informed consent and questioners were administered (see Appendix C). If all the conditions for the experiment were satisfied, the informed consent was signed by the participant and there were no questions to ask from the participant's side, then, the experiment started. The study started with a demographic questionnaire followed by an Affect grid questionnaire and NASA TLX. All the questions participants had to answer were displayed using the web-based survey tool "Qualtrics". After filing the first part of the questionnaire, the participants were assigned to either the control or experimental group. The control group received a 23-minutes long podcast by Dan Gilbert "*Decide already*" (copyright by Creative Commons), which was followed by repeated questionnaires of the Affect grid, NASA TLX and weight question. The experimental group received OMM audio instructions that were based on OMM used by O'Connor et al. (2022) (see Appendix D) and had to engage in meditation for approximately 25 minutes which was followed by filling in the Affect grid, NASA TLX and weight questionnaires. Both conditions listened to the recordings using noise-cancelling headphones. After the participants were asked to take off their shoes and the MSL followed. The MSL tasks consisted of 8 sessions. The first 6 sessions were the training phase where participants practised and learned the two sequences. The 7th and 8th sessions were testing sessions where familiar/novel sequences were played. After the completion of the first 3 sessions, a 10 min break was administered during which participants rested and filled the Affect grind and NASA

TLX questioners. In all other instances, there was a 3-min break between sessions. After participants executed 24 sequences, a 30-second break in the middle of the session followed. After finishing the 6th session, the Affect grid and NASA TLX questioners followed again for the last time. Furthermore, the participant had to answer an additional questionnaire regarding the recall of two sequences and the strategies they used to recall them. After completion of this last questionnaire, participants engaged in familiar/novel sequence conditions which were counterbalanced. After the completion of the 7th and 8th sessions, the participants were debriefed about the experiment and were thanked for their participation. The design of the present study can be seen in Figure 5.

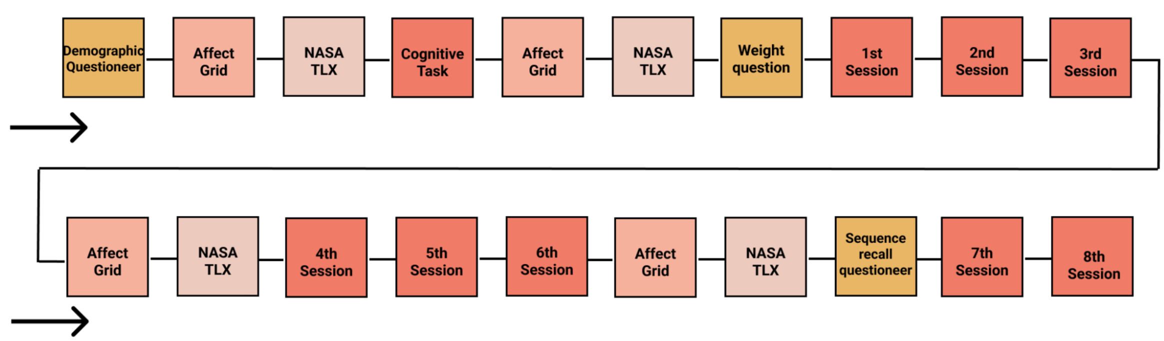


Figure 5. Study design. The study started with demographic questioners which later followed with Affect grid and NASA TLX. Afterwards, the Cognitive task (OMM/podcast) was done which was again followed with the Affect grid and NASA TLX questioners and weight question. The first 3 training sessions were executed followed by the Affect grid and NASA TLX questioners. Afterwards, the last 3 training sessions were done and the Affect grid and NASA TLX questioners were carried out for the last time, additionally, a sequence knowledge questionnaire was implemented. This ended with the 7th and 8th sessions which were testing sessions for familiar/unfamiliar sequences.

2.5 Data analysis

2.5.1 Data filtering

Prior to data analysis, the data from E-Prime® was extracted and converted into an excel file where initial data filtering took place. The RT mean of trial, and accuracy were calculated. Furthermore, the accuracy percentage per session per participant was calculated. Additionally, the step positions of letters “s, w, a, d” were recoded into numbers from 1 to 6. After data filtering was completed in excel, the file was uploaded into RStudio and further processing was performed. The values for the trial-level RT means that were above or below 2.5SD were extracted. In total 4 data frames were created, namely, for training MSL, testing MSL, training MSL (only full trial information), and testing MSL (only full trial information). To classify the data frames variable “Subtrial” was used which represented six numbers “8, 9, 10, 11, 12, 13” that contain step values. An additional number 14 was maintained from the Subtrial which referred to the full trial information such as mean trial reaction time and accuracy for the whole trial of 6 steps.

2.5.2 Data analysis

For the data evaluation, the statistical programming language R was used. The RT mean was analysed with linear mixed effects regression using the lmer4 package. Important to note that for the testing of the accuracy hypothesis, the raw accuracy data was used, in other words, accuracy was not filtered and contained accurate and inaccurate trials. For all the other models the parameter of accuracy was filtered to represent only the fully accurate trials. More precisely, if the participant had even one mistake within the 6-step trial, the whole trial was removed from the analysis.

The data frames containing sessions 1 to 6 had factors created for variables of Subject, Group and Session. When creating the factor for the Session variable it is important to specify that the levels are from 1 to 6 to avoid abnormalities in later data analyses. The choice to use variables as factors in the analysis was based on the Akaike Information Criterion (AIC). The AIC indicates model fit by calculating the value for the model (Vrieze, 2012). The model with a lower AIC value indicates a better fit (Vrieze, 2012). In the present study, the AIC value was smaller for all models that treated variables as factors.

To test the possible changes in accuracy between groups the 1st model was used. The dependent variable of interest was the percentage of accurate trials per session per participant and the independent variables were Group (Control, OMM) and Session 1 to 6. Subject was treated as a random factor to account for possible interclass variance.

The 2nd model was used to investigate the changes between groups in their RTs. The dependent variable was RT and the independent variables were Group (Control, OMM) and Session 1 to 6. The Subject variable was treated as a random factor to account for possible interclass variance. The 1st and 2nd models were used to assess the first hypothesis regarding performance during MSL.

The 3rd model was used to investigate the differences between groups with the unfamiliar/familiar sequence RT performance. The dependent variable was RT and the independent variables were Group (Control and OMM) and sequence familiarity. The Subject was treated as a random factor to account for possible interclass variance. The third model was used to investigate the second hypothesis about group RT performance with familiar/unfamiliar sequences.

The 4th model was used to investigate the concatenation patterns between groups. The dependent variable was RT between steps. The independent variables were Step Position, Group and Session 1 to 6. The Subject variable was treated as a random factor to account for possible interclass variance. The fifth model's dependent variable was RT across steps. Independent variables were Group, Step number, and Familiar/Unfamiliar sequence. The Subject was treated as a random factor. The fourth and fifth models were used to test the 3rd hypothesis about concatenation. The code used to conduct filtering and data analysis in R can be observed in (see Appendix E).

3.0 Results

The first mixed effects model (MEM) analysis looked at accuracy between groups and between learning sessions 1 to 6. No significant main group differences for accuracy were discovered ($\chi2[1, N = 24] = 0.15, p = .69$). There was a significant interaction for accuracy between sessions and group ($\chi2[1, N = 24] = 1129.52, p < .001$) . From the figure, it is visible that both groups start with lower accuracy and the OMM condition is performing worse at the beginning than the control. However, from the 2nd to the 6th session, groups nearly equalise in their accuracy levels (see Figure 6).

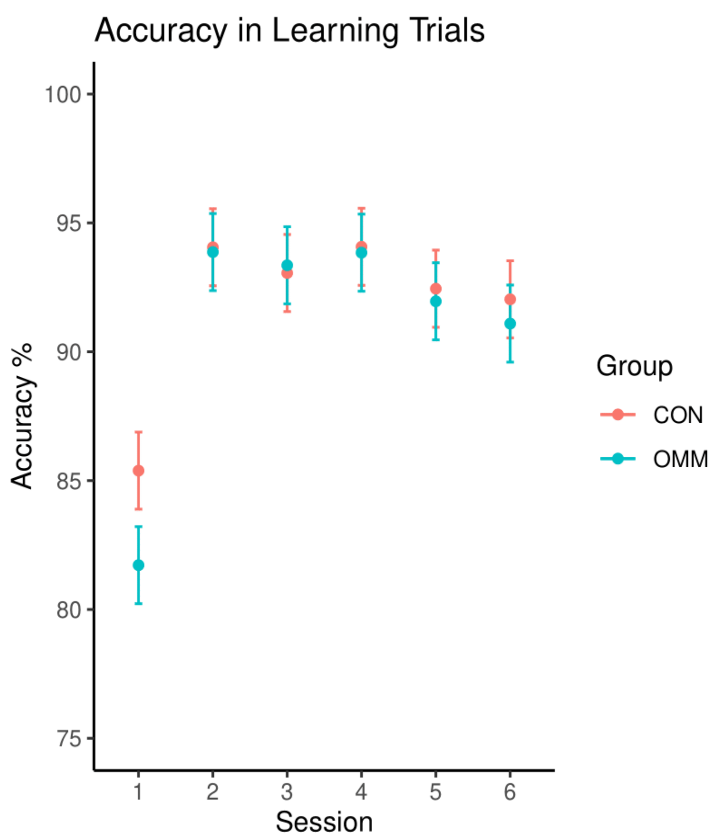


Figure 6. Accuracy - Group*Session interaction. An observable difference between groups is only within the first session with the control group showing more accurate trials than OMM. The following sessions 2 to 6 show a rise in the percentage of accurate trials for both groups. During the last sessions, the control group shows slightly more accurate trials than the OMM condition.

The MEM analysis for the RT across learning sessions 1 to 6 showed no significant main group difference ($\chi2[1,N = 24] = 0.37$, $p = .53$). There was a significant interaction between Group and Session ($\chi2[1,N = 24] = 167.35$, $p < .001$). From the figure, it is visible that the control group initially started faster, however, as the sessions proceeded, the OMM began to catch up and slightly surpassed the control condition within the last session (see Figure 7).

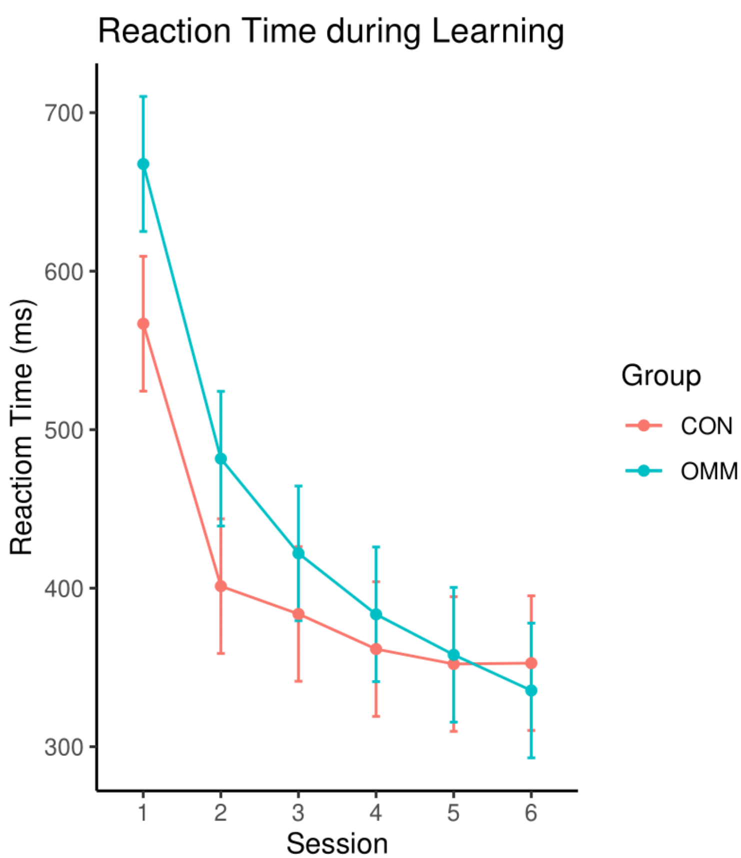


Figure 7. RT mean - Session*Group interaction. The observable differences in the first session between groups with the control group scoring lower RT values than the OMM group. The observable difference in linear slope where OMM condition becomes faster within last sessions and surpasses the slowing control condition. The interaction between Group*Session is observable between 5-6 sessions where the OMM condition becomes faster than the control group.

The MEM analysis for the third module showed that there was no significant main group difference ($\chi2[1,N = 24] = 0.06$, $p = .77$). Following, there was a significant effect of interaction between Group and sequence Familiarity ($\chi2[1,N = 24] = 21.53$, $p < .001$). The figure shows that for familiar sequences both groups performed almost the same. However, for the unfamiliar sequence, the control group showed faster RT values (see Figure 8).

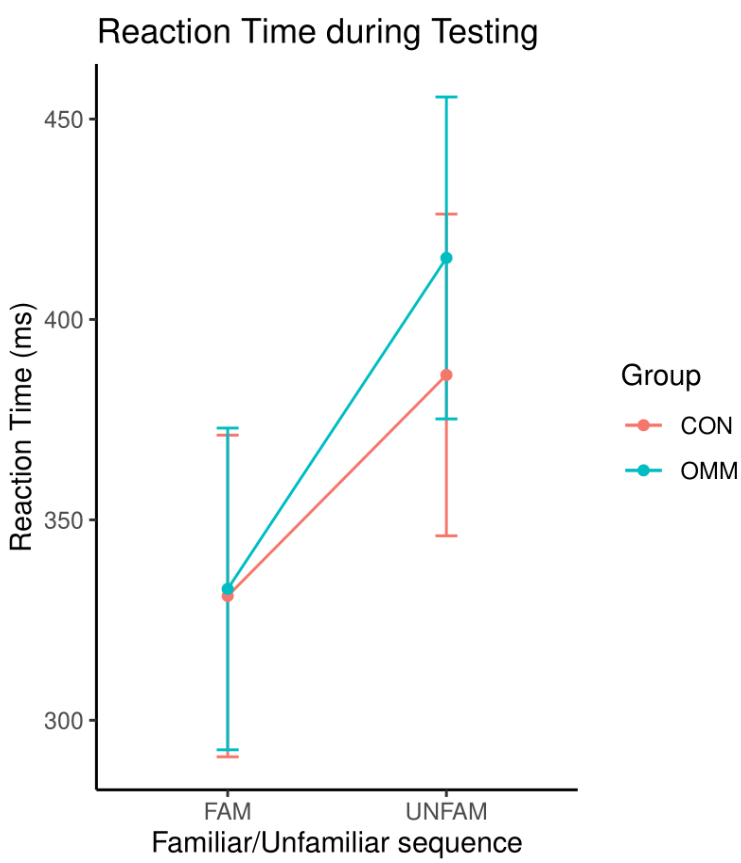


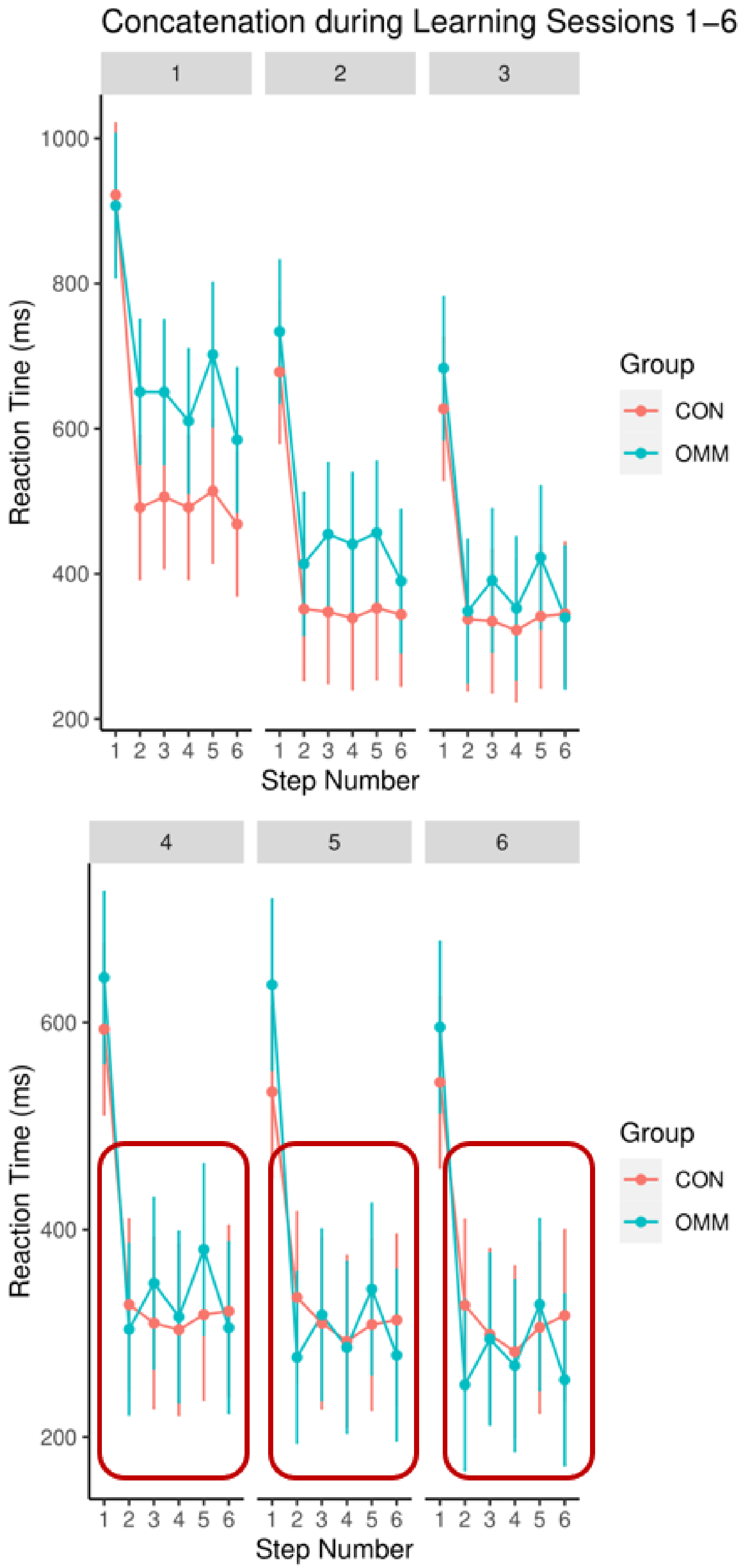
Figure 8. RT mean - Group*FAM/UNFAM interaction. The modelled effect of the 7th and 8th sessions. Observable difference between familiar/unfamiliar conditions. Regarding group-level differences, only the Unfamiliar sequence exhibits that the control condition showed faster values of RT compared to OMM.

The fourth model looked at concatenation performance. No significant main group differences were discovered ($\chi2[1, N = 24] = 0.37$, $p =.53$) There was a significant group and session interaction ($\chi2[5, N = 24] = 279.44$, $p < .001$), group and step position interaction ($\chi2[5, N = 24] = 125.23$, $p < .001$) and group, session and step position interaction ($\chi2[5, N = 24] = 195.25$, $p < .001$). Concatenation patterns were observed in OMM condition. More precisely, the sessions 4 to 6 show a big drop in RT time from the first step to the second and slower RT from 4 to 5 step (see Figure 9). The control group did not show concatenation pattern across MSL sessions.

Table 1.

*Post-hoc interaction analysis of Group*Step number between Sessions. Visible performance decrease for OMM condition from step 4-5 and performance normalisation from 5-6. The control condition did not exhibit such a pattern.*

Session	Group	Step 1-2		Step 2-3		Step 3-4		Step 4-5		Step 5-6	
		Intercept	P-value	Intercept	P-value	Intercept	P-value	Intercept	P-value	Intercept	P-value
1	OMM	256	***					-91	***	117	***
2	OMM	320	***							66	***
3	OMM	334	***					-70	***	82	***
4	OMM	339	***	-44	*	32	*	-64	***	75	***
5	OMM	359	***					-56	**	63	***
6	OMM	344	***					-59	**	72	***
1	CON	430	***							233	*
2	CON	326	***								
3	CON	289	***								
4	CON	265	***								
5	CON	198	***								
6	CON	214	***								



Concatenation during Learning Sessions 1−6
1
2
3
Reaction Tine (ms)
1000
800
600
400
200
1 2 3 4 5 6
Step Number
Group
CON
OMM
4
5
6
Reaction Time (ms)
600
400
200
1 2 3 4 5 6
Step Number
Group
CON
OMM

Figure 9. Concatenation analysis for OMM and control groups across sessions. Insight into differences in the execution of the chunks. The first 3 sessions do not exhibit a chunking pattern. In the 4 to 6 sessions, a chunking behaviour for the OMM condition is observed. More precisely, in steps 4 to 5 concatenation occurs. The red squares are the indication of where the chunking occurs. In the first session, the reaction mode is likely occurring and the control group utilises it better than the OMM condition. In the second and third sessions, we can observe that the OMM group starts to catch up with the control group and execute somewhat small chunks. Subsequently, the OMM condition is likely engaged in the associative mode in the second and third sessions. The flat line for the control group, which later progressed to a “V” shape, suggests that participants were likely engaged in the reaction mode during all the sessions.

The fifth model investigated the concatenation performance for Familiar/unfamiliar sequences. No significant main group differences were discovered ($\chi2[1,N = 24] = 0.06$, $p = .79$). There was a significant interaction for group/familiar unfamiliar sequence ($\chi2[1,N = 24] = 26.56$, $p < .001$), significant interaction for group/step number ($\chi2[5,N = 24] = 178.30$, $p < .001$) and significant interaction between variables of group, familiar/unfamiliar sequence and step number ($\chi2[5,N = 24] = 40.79$, $p < .001$). The OMM condition showed concatenation patterns for the familiar sequence, but not for the unfamiliar sequence (see Figure 10). The control group did not exhibit concatenation for both sequence conditions.

Table 2.

*Post hoc analysis of Group*Step number between Fam/Unfam sessions. Visible performance decrease for OMM condition from steps 4-5 and performance normalisation from 5-6 only in FAM session.*

Session	Group	Step 1-2		Step 2-3		Step 3-4		Step 4-5		Step 5-6	
		Intercept	P-value	Intercept	P-value	Intercept	P-value	Intercept	P-value	Intercept	P-value
FAM	OMM	357	***	-44	***	30	*	-65	***	73	***
UNFAM	OMM	355	***								
FAM	CON	224	***								
UNFAM	CON	272	***					35	**		

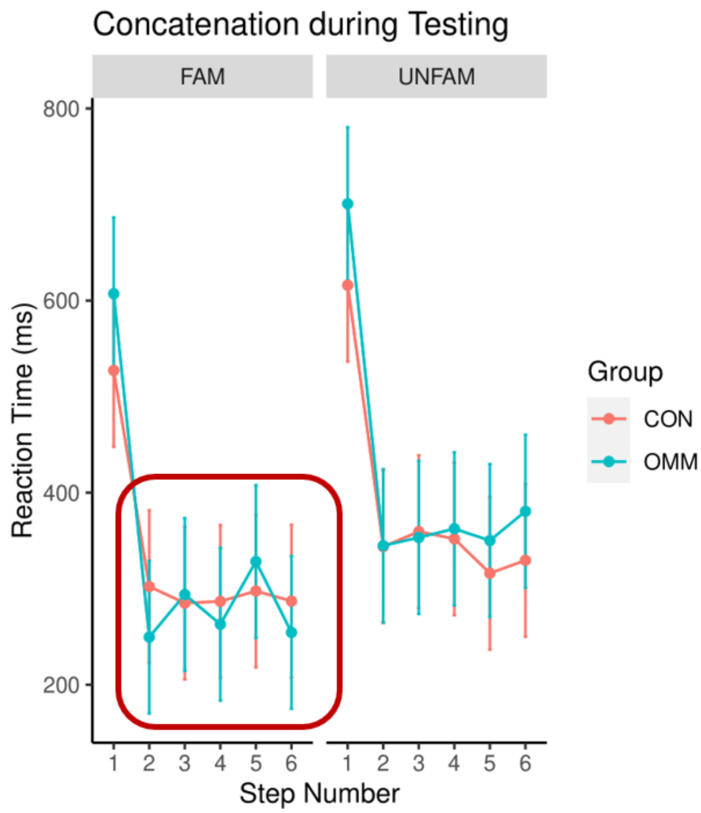


Figure 10. Concatenation for familiar/unfamiliar sequence between Control and OMM groups. An observable difference is seen from the first step to the second with vastly decreased RT. Furthermore, the OMM condition shows chunking patterns for the familiar sequence but not for the unfamiliar sequence. The control group does not exhibit concatenation patterns for both sequences. The red square indicates where chunking is occurring in the OMM condition. The weaker OMM performance in unfamiliar sequence could be explained by weakened top-down cognitive control. OMM condition needs more time to adapt to new sequences because of the biased cognitive state.

4.0 Discussion

The present study investigated how OMM affects groups in MSL using a dance-step version of the DSP task. The first hypothesis stated that participating in the OMM condition would result in increased performance compared to the control condition during MSL. Results regarding accuracy showed no significant group difference but a significant Group*Session interaction. The OMM condition began with a lower percentage of accurate trials but later equalised itself to the control condition. The significant interaction likely to have occurred from the first session to the second because a big increase in accuracy was observed for both groups. Furthermore, regarding the RTs the results showed no significant group difference, but a significant interaction between Session*Group. The visualisation of the data showed that the linear slope predicted that the OMM would show faster RT values. Such a tendency is notable between learning Sessions 5 and 6.

The second hypothesis investigated whether participating in the OMM condition would result in higher RTs with the unfamiliar sequence compared to the control condition during MSL. The results showed faster control group RTs than the OMM condition with the unfamiliar sequence. The results support our hypothesis that the OMM group would show slower RTs with an unfamiliar sequence compared to the control group.

The third hypothesis predicted that participating in the OMM would lead to a cognitive control state that favours chunking more than the control group during MSL. The results supported our hypothesis. The concatenation plots indicated that for the OMM group chunking behaviour was evident which was most visible from the 4th session to the 6th session during the training phase and for the familiar sequence during the testing phases. The control group did not exhibit any indication that would suggest that the group used chunking mode. Moreover, it should be reminded that RT performance was faster in the OMM group, possible because of increased chunking utilisation.

During the first session, the results show that both groups were engaging in the reaction mode and slowly the sequence-specific knowledge was acquired. During these first sessions, the control group showed better performance in terms of faster RTs value and higher accuracy than the OMM condition. This allows to reason that the control group utilised the reaction mode better than the OMM group. An explanation for this occurrence could be explained by the OMM influence on cognitive control states, namely, weakening the top-down information processing and the idea that more time is required for the OMM group, in the beginning, to react to stimuli having a wider scope of awareness (Colzato et al., 2016; Valentine & Sweet 1999).

During the last sessions, the OMM condition began to outperform the control group. This became possible because the OMM condition likely began to engage in chunking mode. Support for this prediction is visible from concatenation plots where comparable patterns to chunking behaviour emerged to the ones provided in the study of Abrahamse et al. (2013). The present study concatenation plot for the OMM group clearly shows the first slow initiation response followed by a fast execution phase and concatenation point at the 5th step. The control group did not exhibit such a pattern.

The acquired results suggest that there was an OMM effect on MSL. More precisely, the slow and inaccurate start was probably because participants were adapting to new the task and because of weakened top-down processing. However, in later sessions, the OMM group began to engage in chunking mode. This could be explained by the enhanced problem-solving and creative approach tendencies after OMM (Colzato et al., 2015; Colzato et al., 2016; Lippelt et al., 2014, Amer et. al., 2016). The idea that the OMM group was enhanced by meditation is further supported by looking at the concatenation testing sessions 7 and 8. For the familiar sequence, the OMM exhibited similar concatenation patterns as in training sessions 4 to 6 and had faster RTs than the control group. However, once the sequence changed to unfamiliar, the chunking pattern disappeared. An explanation for this could be that the OMM condition requires more time to adapt to a new task. The findings go in line with the prediction that for the OMM group the cognitive flexibility state is still there in that it takes a longer time to integrate the new sequence (Immink et al., 2017). This is further supported by the testing analysis for the 7th and 8th sessions. More specifically, the findings that the OMM condition performed slower RTs for the unfamiliar sequence compared to the control condition. This might be explained by the prediction that OMM group cognitive control states were enhanced for creativity and flexibility rather than the vigilant track of changing stimulus (Colzato et al., 2015; Colzato et al., 2016; Lippelt et al., 2014, Amer et. al., 2016).

4.1 Comparison to previous studies

According to Colzato et al. (2016), the OMM weakens the top-down information processing cycle. In turn, this allows people to be more flexible in regard to tasks that require a substantial amount of cognitive control integration like MSL. This may explain why in the present study we found that the OMM condition exhibited inferior RTs and accuracy parameters in the early stage of MSL and in the end showed superior RTs compared to the control group. It is possible to state that because of the weakened top-down information processing, participants in the OMM condition were engaging in a more creative problem-solving state. The enhanced problem-solving creativity might be attributed to the idea that the OMM condition was engaging in the chunking mode to reproduce the sequences.

The present experiment used the DS-DSP task to investigate whether OMM enhances MSL. Taking into account that more complex motor movements were involved, namely, footsteps, the present study, nevertheless, yielded comparable results to other papers that were using finger key-press sequences for MSL investigation. Firstly, the present study results show that the OMM condition demonstrates slower RT values compared to the control group in most sessions, however, based on the linear slope projections, it seems to predict that the OMM condition would outperform the control group in terms of faster RTs. The results could be seen as similar to the study results of Immink et al. (2017), where it was observed that the meditation condition of OMM showed faster values of RT compared to the control group. In support, the study of Chan et al. (2016) yielded similar results for the FAM condition. In other words, participants who received FAM prior to MSL showed enhanced MSL performance following a single meditation session. It is important to note that FAM induces top-down information processing and reaction mode which is different from the OMM effects on cognitive controls. The current study results may possibly expand the former report by showing that next to FAM, the OMM condition might be able to enhance the MSL performance. The present paper's findings on meditation enhancement of MSL are likely to support the growing body of research that meditation prior to MSL is able to enhance cognitive functions in tasks where the results rely on attentional control (Colzato et al., 2015; Colzato et al., 2016; Tang et al., 2007).

Furthermore, in the present study, it was observed that the OMM condition performed slower with unfamiliar sequences than the control group. The finding is supported by Immink et al. (2017), where it was found that the novel sequences disturbed the OMM condition significantly more than the control group. The reason, why performance diminished for the unfamiliar sequence for the OMM condition, could be explained by the idea that the OMM group still tried to implement the old sequence responding modes, while the sequence arrangement changed with the unfamiliar sequence session.

4.2 Limitations

The first limitation of the present study is regarding the possible insensitivity of the dance-mat that participants were using. Some participants have indicated that the dance pad mat did not record their steps even though they were sure they made the correct sequence combinations. This interference caused some participants to experience frustration and reduced motivation due to the inaccurately recorded performance. The issue could be solved by acquiring a new dance pad with higher sensitivity.

The following limitation could be marked as the ceiling effect regarding the sequence accuracy testing. Participants who perform the DSP task tend to exhibit a high percentage of accurate trials. This could make the parameter of accuracy experience a ceiling effect, where the score of accuracy does not have enough space to represent the performance. This issue could be fixed by extending the stimuli in a sequence so that it would become more complex to obtain higher values of accuracy.

4.3 Future research

In a study by Chan et al. (2017), researchers have included a meditation condition with a rest period of 22 minutes. The results showed that the participants that received the rest period after meditation outperformed the control group and just the meditation group with no rest period

(Chan et al., 2017). Future research could investigate whether similar tendencies would be observable also for the OMM condition.

Furthermore, according to Malinowski (2013), the meditation conditions for mindfulness training of FAM and OMM overlap when it comes the practical implementation. Most commonly participants would first engage in FAM which would promote attentional stability and the presence of the mental state. Soley then it could be feasible to start engaging in valid OMM practice. With continuous training, a person would become less reliant on the FAM condition to purposely engage in OMM (Malinowski, 2013). Future research could try to investigate whether the combination of firstly FAM and later OMM conditions boosts the effect significantly more on the MSL performance rather than a single OMM session.

4.4 Conclusion

The present experiment provided an important insight into OMM enhancement during dance step MSL. There were observable differences in group performance during the MSL. The results show that a single session of OMM may seem to have an influence on cognitive control states that influenced the MSL performance. This was observed by the OMM condition engagement in chunking mode during the MSL. It is possible to argue that the reason why OMM showed chunking behaviour and the control group did not is that the OMM condition cognitive control states were biased to engage in creative problem-solving. Furthermore, the present study observed that OMM has an influence on dance-step sequence learning which may be an important finding since most studies investigating cognitive control function connections with the MSL are conducted with finger key-press sequence testing.

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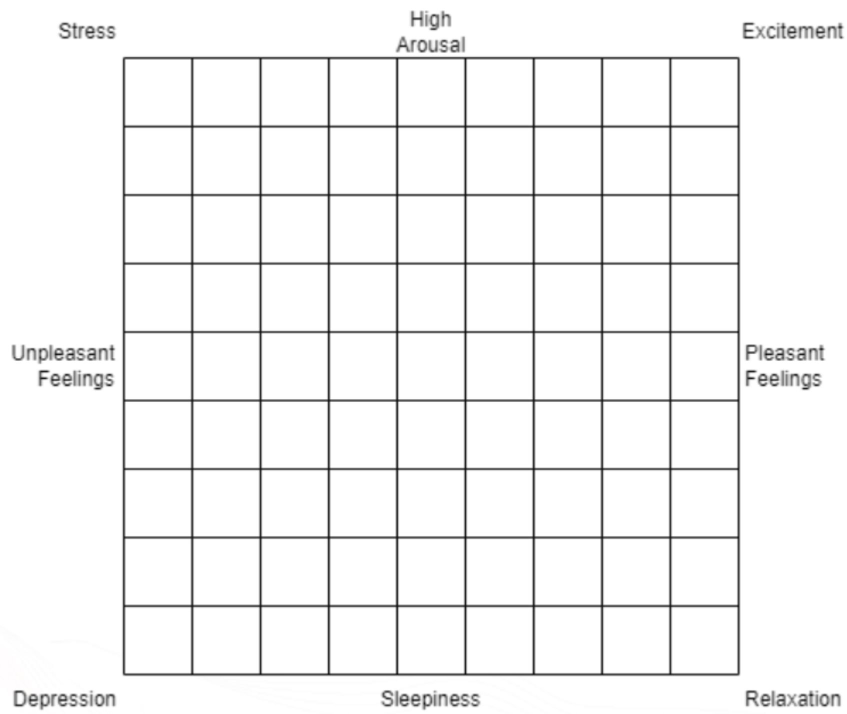
Appendix A

Effect grid (in qualtrics)

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



Appendix B

NASA TLX questionnaire (in qualtrics)

Mental demand. How mentally demanding was the task?

very low very high

1 21

move slider to indicate

Physical demand. How physically demanding was the task?

very low very high

1 21

move slider to indicate

Temporal demand. How hurried or rushed was the task?

very low very high

1 21

move slider to indicate

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

very low very high

1 21

move slider to indicate

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

very low very high

1 21

move slider to indicate

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

very low very high

1 21

move slider to indicate

Appendix C

Informed consent for the study

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:

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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 D

OMM meditation recording transcribed

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 E

R Code for the data filtering and analysis

```
```{r}
library(devEMF)
library(wrapr)
library(writexl)
library(lme4)
library(readxl)
library(haven)
library(effects)
library(lattice)
library(car)
library(ggplot2)
library(knitr)
library(reshape2)
library(dplyr)
library(forcats)
library(DHARMa)
library(Hmisc)
library(phia)
library(lsmeans)
library(emmeans)
library(multcomp)
library(plotly)
library(lmerTest)
library(readxl)
library(tinytex)
library(tidyverse)
library(haven)
library(broom)
library(tidyverse)
library(dplyr)
library(AICcmodavg)
library(janitor)
library(psych)
library(corrplot)
library(devtools)
```

```{r}
setwd("C:/Users/31616/Desktop/Bachelor thesis")
```

```{r}
df_data <- read_xlsx("FAMOMCON_Final.xlsx")

df_data_OMM <- filter(df_data, Group %in% c("OMM","CON"))

df_data_acc <- read_xlsx("sm acc.xlsx")

df_data_acc <- df_data_acc %>% select(-(Row_Labels:Sum_8))

df_data_OMM<- merge(df_data_acc, df_data_OMM, by = c("Subject","Session", "FAM_UNFAM", "Group"))

```
```

```
#Filtering the 2.5SD and creating dataframe
```{r}
beer_1 <-filter(df_data_OMM, Session == 1)

mean(beer_1$feedback.RT.mean)

sd(beer_1$feedback.RT.mean)

#2

beer_2 <-filter(df_data_OMM, Session == 2)

mean(beer_2$feedback.RT.mean)

sd(beer_2$feedback.RT.mean)

#3

beer_3 <-filter(df_data_OMM, Session == 3)

mean(beer_3$feedback.RT.mean)

sd(beer_3$feedback.RT.mean)

#4

beer_4 <-filter(df_data_OMM, Session == 4)

mean(beer_4$feedback.RT.mean)

sd(beer_4$feedback.RT.mean)

#5

beer_5 <-filter(df_data_OMM, Session == 5)

mean(beer_5$feedback.RT.mean)

sd(beer_5$feedback.RT.mean)


#6

beer_6 <-filter(df_data_OMM, Session == 6)

mean(beer_6$feedback.RT.mean)

sd(beer_6$feedback.RT.mean)

#7FAM

beer_7FA <-filter(df_data_OMM, Session == 7, FAM_UNFAM == "FAM")

mean(beer_7FA$feedback.RT.mean)

sd(beer_7FA$feedback.RT.mean)

#7UNFAM

beer_7UN <-filter(df_data_OMM, Session == 7, FAM_UNFAM == "UNFAM")

mean(beer_7UN$feedback.RT.mean)

sd(beer_7UN$feedback.RT.mean)
```
```

```
mean(beer_6$feedback.RT.mean)

sd(beer_6$feedback.RT.mean)

#7FAM

beer_7FA <-filter(df_data_OMM, Session == 7, FAM_UNFAM == "FAM")

mean(beer_7FA$feedback.RT.mean)

sd(beer_7FA$feedback.RT.mean)

#7UNFAM

beer_7UN <-filter(df_data_OMM, Session == 7, FAM_UNFAM == "UNFAM")

mean(beer_7UN$feedback.RT.mean)

sd(beer_7UN$feedback.RT.mean)

#8FAM

beer_8FA <-filter(df_data_OMM, Session == 8, FAM_UNFAM == "FAM")

mean(beer_8FA$feedback.RT.mean)

sd(beer_8FA$feedback.RT.mean)

#8UNFAM

beer_8UN <-filter(df_data_OMM, Session == 8 & FAM_UNFAM == "UNFAM")

mean(beer_8UN$feedback.RT.mean)

sd(beer_8UN$feedback.RT.mean)


####Filtering out the values
data_1 <- filter(df_data_OMM, Session == 1 & feedback.RT.mean < 1447)
data_2 <- filter(df_data_OMM, Session == 2 & feedback.RT.mean < 942)
data_3 <- filter(df_data_OMM, Session == 3 & feedback.RT.mean < 948)
data_4 <- filter(df_data_OMM, Session == 4 & feedback.RT.mean < 825)
data_5 <- filter(df_data_OMM, Session == 5 & feedback.RT.mean < 775)
data_6 <- filter(df_data_OMM, Session == 6 & feedback.RT.mean < 757)
data_7FA <- filter(df_data_OMM, Session == 7 & feedback.RT.mean < 732)
data_7UN <- filter(df_data_OMM, Session == 7 & feedback.RT.mean < 751)
data_8FA <- filter(df_data_OMM, Session == 8 & feedback.RT.mean < 651)
data_8UN <- filter(df_data_OMM, Session == 8 & feedback.RT.mean < 842)



df_data_OMM <- rbind(data_1, data_2, data_3, data_4, data_5, data_6, data_7FA,data_7UN, data_8FA, data_8UN)

'''

#Creating factors for Accuracy analysis.

'''{r}
df_data_OMM_14_test <- filter(df_data_OMM, SubTrial == 14 & Session %in% c(7,8))

df_data_OMM_14_train <- filter(df_data_OMM, SubTrial == 14 & Session %in% c(1,2,3,4,5,6))


df_data_OMM_test <- filter(df_data_OMM, SubTrial %in% c(9,11,13,8,10,12) & Session %in% c(7,8))

df_data_OMM_train <- filter(df_data_OMM, SubTrial %in% c(9,11,13,8,10,12) & Session %in% c(1,2,3,4,5,6))
'''
#Thesing Accuracy hypothesis Accuracy = Group*Session
```

```
#Thesing Accuracy hypothesis Accuracy = Group*Session
```{r}
df_data_OMM_train$Subject <- factor(df_data_OMM_train$Subject)
df_data_OMM_train$Group <- factor(df_data_OMM_train$Group)
df_data_OMM_train$Session <- factor(df_data_OMM_train$Session, ordered = TRUE, levels=c('1', '2', '3', '4', '5', '6'))


m.df_H3 <- lmer(Percentage ~ Group*Session + (1|Subject), data=df_data_OMM_train, REML = FALSE)
Anova(m.df_H3)
summary(m.df_H3, df="Satterthwaite")

plot(m.df_H3)

ae.m.H3 <- allEffects(m.df_H3)
ae.m.df.H3 <- as.data.frame(ae.m.H3[[1]])

H3 <- ggplot(ae.m.df.H3, aes(x=Session, y=fit, color = Group)) +
  geom_errorbar(aes(ymin=fit-se, ymax=fit+se), width=.1) +
  geom_line() +
  geom_point() +
  ylab("Accuracy %") +
  xlab("Session") +
  ggtitle("Accuracy in Learning Trials") +
  scale_y_continuous(limits=c(75,100))+
  theme_classic()

print(H3)
```


#Reuploading the data for following analyses where only accurate trials are used.


```{r}
df_data <- read_xlsx("FAMOMCON_Final.xlsx")

df_data_OMM <- filter(df_data, Group %in% c("OMM","CON"))


df_data_OMM <- filter(df_data_OMM, feedback.ACC.trial == 1)


beer_1 <-filter(df_data_OMM, Session == 1)

mean(beer_1$feedback.RT.mean)

sd(beer_1$feedback.RT.mean)

#2

beer_2 <-filter(df_data_OMM, Session == 2)

mean(beer_2$feedback.RT.mean)

sd(beer_2$feedback.RT.mean)

#3

beer_3 <-filter(df_data_OMM, Session == 3)

mean(beer_3$feedback.RT.mean)

sd(beer_3$feedback.RT.mean)
```
```

```
#4
beer_4 <-filter(df_data_OMM, Session == 4)
mean(beer_4$feedback.RT.mean)
sd(beer_4$feedback.RT.mean)
#5
beer_5 <-filter(df_data_OMM, Session == 5)
mean(beer_5$feedback.RT.mean)
sd(beer_5$feedback.RT.mean)

#6
beer_6 <-filter(df_data_OMM, Session == 6)
mean(beer_6$feedback.RT.mean)
sd(beer_6$feedback.RT.mean)
#7FAM
beer_7FA <-filter(df_data_OMM, Session == 7, FAM_UNFAM == "FAM")
mean(beer_7FA$feedback.RT.mean)
sd(beer_7FA$feedback.RT.mean)
#7UNFAM
beer_7UN <-filter(df_data_OMM, Session == 7, FAM_UNFAM == "UNFAM")
mean(beer_7UN$feedback.RT.mean)
sd(beer_7UN$feedback.RT.mean)
#8FAM
beer_8FA <-filter(df_data_OMM, Session == 8, FAM_UNFAM == "FAM")
mean(beer_8FA$feedback.RT.mean)
sd(beer_8FA$feedback.RT.mean)
#8UNFAM
beer_8UN <-filter(df_data_OMM, Session == 8 & FAM_UNFAM == "UNFAM")
mean(beer_8UN$feedback.RT.mean)
sd(beer_8UN$feedback.RT.mean)

####Filtering out the values
data_1 <- filter(df_data_OMM, Session == 1 & feedback.RT.mean < 1447)
data_2 <- filter(df_data_OMM, Session == 2 & feedback.RT.mean < 942)
data_3 <- filter(df_data_OMM, Session == 3 & feedback.RT.mean < 948)
data_4 <- filter(df_data_OMM, Session == 4 & feedback.RT.mean < 825)
data_5 <- filter(df_data_OMM, Session == 5 & feedback.RT.mean < 775)
data_6 <- filter(df_data_OMM, Session == 6 & feedback.RT.mean < 757)
data_7FA <- filter(df_data_OMM, Session == 7 & feedback.RT.mean < 732)
data_7UN <- filter(df_data_OMM, Session == 7 & feedback.RT.mean < 751)
data_8FA <- filter(df_data_OMM, Session == 8 & feedback.RT.mean < 651)
data_8UN <- filter(df_data_OMM, Session == 8 & feedback.RT.mean < 842)
```

```
df_data_OMM <- rbind(data_1, data_2, data_3, data_4, data_5, data_6, data_7FA,data_7UN, data_8FA, data_8UN)


df_data_OMM_14_test <- filter(df_data_OMM, SubTrial == 14 & Session %in% c(7,8))

df_data_OMM_14_train <- filter(df_data_OMM, SubTrial == 14 & Session %in% c(1,2,3,4,5,6))


df_data_OMM_test <- filter(df_data_OMM, SubTrial %in% c(9,11,13,8,10,12) & Session %in% c(7,8))

df_data_OMM_train <- filter(df_data_OMM, SubTrial %in% c(9,11,13,8,10,12) & Session %in% c(1,2,3,4,5,6))



```


#Creating factors
```{r}
df_data_OMM_step_train <- filter(df_data_OMM_train, step.number %in% c(1,2,3,4,5,6))


df_data_OMM_step_train$Subject = factor(df_data_OMM_step_train$Subject)
df_data_OMM_step_train$Group = factor(df_data_OMM_step_train$Group)
df_data_OMM_step_train$Session = factor(df_data_OMM_step_train$Session, ordered = TRUE, levels=c('1', '2', '3', '4', '5', '6'))
df_data_OMM_step_train$step.number = factor(df_data_OMM_step_train$step.number)

df_data_OMM_step_test <- filter(df_data_OMM_test, step.number %in% c(1,2,3,4,5,6))

df_data_OMM_step_test$Subject = factor(df_data_OMM_step_test$Subject)
df_data_OMM_step_test$Group = factor(df_data_OMM_step_test$Group)
df_data_OMM_step_test$FAM_UNFAM = factor(df_data_OMM_step_test$FAM_UNFAM)
df_data_OMM_step_test$step.number = factor(df_data_OMM_step_test$step.number)

```


#Testing 1st Hypothesis. RT = Group*Session
```{r}
df_data_OMM_14_train$Subject <- factor(df_data_OMM_14_train$Subject)
df_data_OMM_14_train$Group <- factor(df_data_OMM_14_train$Group)
df_data_OMM_14_train$Session <- factor(df_data_OMM_14_train$Session, ordered = TRUE, levels=c('1', '2', '3', '4', '5', '6'))

m.df_H1 <- lmer(feedback.RT.mean ~ Group*Session + (1|Subject), data=df_data_OMM_14_train, REML = FALSE)
Anova(m.df_H1)
summary(m.df_H1, df="Satterthwaite")

plot(m.df_H1)


ae.m.H1 <- allEffects(m.df_H1)
ae.m.df.H1 <- as.data.frame(ae.m.H1[[1]])


H1 <- ggplot(ae.m.df.H1, aes(x=Session, y=fit,group = Group, color = Group)) +
  geom_errorbar(aes(ymin=fit-se, ymax=fit+se), width=.1) +
  geom_line() +
  geom_point() +
  ylab("Reactiom Time (ms)") +
  xlab("Session") +
  ggtitle("Reaction Time during Learning") +
  scale_color_manual(labels = c("CON", "OMM"),
  values = c("#F8766D", "#00BFC4"))+
  theme_classic()

print(H1)

lsmeans(m.df_H1, pairwise ~ Group | Session )
```

```
#Testing 2nd Hypothesis: RT = Group*FAM/UNFAM

```{r}
df_data_OMM_test$Subject <- factor(df_data_OMM_test$Subject)
df_data_OMM_test$Group <- factor(df_data_OMM_test$Group)
df_data_OMM_test$FAM_UNFAM <- factor(df_data_OMM_test$FAM_UNFAM)


m.df_H2 <- lmer(feedback.RT.mean ~ Group*FAM_UNFAM + (1|Subject), data=df_data_OMM_14_test, REML = FALSE)
Anova(m.df_H2)
summary(m.df_H2, df="Satterthwaite")

plot(m.df_H2)

ae.m.H2 <- allEffects(m.df_H2)
ae.m.df.H2 <- as.data.frame(ae.m.H2[[1]])

H2 <- ggplot(ae.m.df.H2, aes(x=FAM_UNFAM, y=fit,group = Group, color = Group)) +
  geom_errorbar(aes(ymin=fit-se, ymax=fit+se), width=.1) +
  geom_line() +
  geom_point() +
  ylab("Reaction Time (ms)") +
  xlab("Familiar/Unfamiliar sequence") +
  ggtitle("Reaction Time during Testing") +
  scale_color_manual(labels = c("CON","OMM"),
  values = c("#F8766D", "#00BFC4"))+
  theme_classic()

print(H2)

lsmeans(m.df_H2, pairwise ~ Group | FAM_UNFAM)
```

4th Hypothesis. Concatenation analyis: RT step level = Group*Step_number*


```{r}
df_data_OMM_step_train_1 <- df_data_OMM_step_train %>% filter(Session %in% c(1,2,3))

df_data_OMM_step_train_2 <- df_data_OMM_step_train %>% filter(Session %in% c(4,5,6))

m.df_H7 <- lmer(feedback.RT ~ Group * Session * step.number + (1|Subject), data=df_data_OMM_step_train_1, REML = FALSE)
Anova(m.df_H7)
summary(m.df_H7, df="Satterthwaite")

plot(m.df_H7)


ae.m.H7 <- allEffects(m.df_H7)
ae.m.df.H7 <- as.data.frame(ae.m.H7[[1]])

#Printing Session effects facet

ae.H7<- ggplot(ae.m.df.H7, aes(x=step.number,y=fit, color=Group))+
geom_line() +
geom_path(aes(x=step.number, y=fit,group = Group, color=Group)) +
geom_errorbar(aes(ymin=lower, ymax=upper), width=.1) +
geom_point(aes(color = Group))+
ylab("Reaction Tine (ms)")+
  xlab("Step Number")+
#scale_x_continuous(name="Se", breaks=c(1,2,3) , limits=c(0.75,3.25))+
ggtitle("Concatenation during Learning Sessions 1-6")+
theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(),panel.background = element_blank(), axis.line = element_line(colour = "black"))+
  scale_color_manual(labels = c("CON","OMM"),
  values = c("#F8766D", "#00BFC4"))+
facet_grid(.~Session)

plot(ae.H7)
```
```

```
m.df_H8 <- lmer(feedback.RT ~ Group * Session * step.number + (1|Subject:Session), data=df_data_OMM_step_train_2, REML = FALSE)
Anova(m.df_H8)
summary(m.df_H8, df="Satterthwaite")

plot(m.df_H8)


ae.m.H8 <- allEffects(m.df_H8)
ae.m.df.H8 <- as.data.frame(ae.m.H8[[1]])

#Printing Session effects facet

ae.H8<- ggplot(ae.m.df.H8, aes(x=step.number,y=fit, color=Group))+
geom_line() +
geom_path(aes(x=step.number, y=fit,group = Group, color=Group)) +
geom_errorbar(aes(ymin=lower, ymax=upper), width=.1) +
geom_point(aes(color = Group))+
ylab("Reaction Time (ms)")+
  xlab("Step Number") +
#scale_x_continuous(name="Se", breaks=c(1,2,3) , limits=c(0.75,3.25))+
ggtitle("Concatenation during Learning Sessions 4-6")+
theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(),panel.background = element_blank(), axis.line = element_line(colour = "black"))+
  scale_color_manual(labels = c("CON","OMM"),
  values = c("#F8766D","#00BFC4"))+
facet_grid(.~Session)

plot(ae.H8)


m.df_H5 <- lmer(feedback.RT ~ Group * FAM_UNFAM * step.number + (1|Subject), data=df_data_OMM_step_test, REML = FALSE)
Anova(m.df_H5)
summary(m.df_H5, df="Satterthwaite")

plot(m.df_H5)


ae.m.H5 <- allEffects(m.df_H5)
ae.m.df.H5 <- as.data.frame(ae.m.H5[[1]])

#Printing Session effects facet

ae.H5<- ggplot(ae.m.df.H5, aes(x=step.number,y=fit,group = Group, color=Group))+
geom_line() +
geom_path(aes(x=step.number, y=fit, color=Group)) +
geom_errorbar(aes(ymin=lower, ymax=upper), width=.1) +
geom_point(aes(color = Group))+
ylab("Reaction Time (ms)")+
  xlab("Step Number")+
#scale_x_continuous(name="Se", breaks=c(1,2,3) , limits=c(0.75,3.25))+
ggtitle("Concatenation during Testing")+
theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(),panel.background = element_blank(), axis.line = element_line(colour = "black"))+
  scale_color_manual(labels = c("CON","OMM"),
  values = c("#F8766D", "#00BFC4"))+
facet_grid(.~FAM_UNFAM)

plot(ae.H5)


```
```
```