Investigating the Spatial and Body Representation of Motor Learning through Bimanual Chord Practice

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June 28, 2023

University of Twente

Bachelor Thesis, Psychology

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Abstract

The current study investigated the suggestion that motor learning includes the learning of spatial representations and/or hand postures. This research question was explored with a chording task. In the practice phase of the experiment, sixteen participants practiced two 4-key chords, made up of two fingers of each hand. These chords were shown on a computer screen and the participants responded to the stimuli on a keyboard. After 7 blocks of around 20 minutes practise, the participants were presented with the same chords, as well as mirrored versions across one hand, mirrored versions across both hands, and two novel chords. The results indicated that learning did take place, as there was a significant difference in reaction time between the practised and novel chords in the test phase. However, there was no significant difference between both the mirrored chords and the novel chords, suggesting that there is no positive transfer of learning when performing the mirrored versions of learned movements. Even though the results were not significant, the data did point to the hypothesised direction. To conclude, more research needs to be conducted to further investigate this research question.

Introduction

After many hours of practice, musicians can perform a music piece automatically, sometimes even while blindfolded. These individuals master the complex motor movements that accompany the piece (Yokoi & Diedrichsen, 2019). This leads to the interesting question of how our cognitive system accomplishes this learning of motor movements. What happens in the brain that makes individuals able to execute such intricate and complex motor movements? Common in the field of music are chords. Chords are keys of an instrument or keyboard pressed simultaneously, creating one sound (Britannica, 2023). Because of the growing interest in how motor learning works, the aim of the present study is to investigate one of two explanations for chord learning. There are indications that motor learning involves the learning of bodily postures at the motor level (Rosenbaum, 1995). In terms of chords, this would be the learning of hand postures used for executing chords. It is also possible that spatial representations of the hand in relation to the body and its surroundings are developed at the central-cognitive level (Rosenbaum et al., 2001). The current study examined to what extent these two explanations are involved in learning motor movements through the analysis of an experimental chording task.

To dive deeper into this research question, the structure of the brain should be touched upon. The motor cortex, responsible for movements and thus playing chords, comprises three frontal lobe areas located in both hemispheres (Evarts, 1973). A subregion of the motor cortex is the premotor cortex, which is responsible for storing learned movements (Kantak et al., 2012). While practising chords, the execution of the chords shifts slowly from being a response to a visual stimulus to a response based on the recognition of stored movements and the spatial representation associated with the familiar chord. The concept *hand posture* entails the posture of the hand at a given moment. The motor cortex is responsible for executing the motor programme used for the specific posture and can thus, with practise, replicate the same hand posture easily (Brooks, 1983). The concept s*patial representation* describes the way in which information about one's environment and their body in relation to this environment are formed and stored in the brain (Olson & Bialystok, 1983). For chording, the position of the keys on the keyboard and the distance between the to-be-pressed keys makes up the spatial representation. So, it is assumed that playing a learned chord with the other hand triggers the contralateral area in the motor cortex, as the spatial representation and hand posture used for the chord stays identical. The concept *transfer of learning* describes this assumption. Transfer entails that prior experiences influence the learning of new skills (Magill & Anderson, 2018). The transfer can be positive, neutral, or negative. Positive transfer means that the previous experience helps the learning of the new skill, whereas negative transfer means that the previous experience hinders the learning of the new skill.

The term spatial representation is closely related to one of the main findings of Michael Graziano. Together with Gross, he described a neural network in the brain that codes the space close to the body (Graziano & Gross, 1993). These multisensory neural networks respond to both touch and vision, and activity in these neurons indicates the close presence of an object. Interestingly, electrical stimulation of a specific area of this neural network led to protective actions such as flinching and blocking (Graziano et al., 1999). These neurons thus play a key role in the perception of peripersonal space and provide a basis for the planning and execution of corresponding behaviours.

One of the oldest documented studies into chording tasks is that of Seibel (1962), whereby participants respond to stimuli that corresponded with five keys on a keyboard. He found that with practice, the Reaction Time (RT) of the learnt chords decreased. At the same time, error rates did not significantly increase. In following years, researchers have investigated different hypotheses using alterations to chording tasks like that of Seibel. Research by Teixeira (2000), for instance, investigated bilateral transfer of learning regarding anticipatory timing and force control of motor movements. In his experiment, the participants pressed a switch with one finger of either their preferred hand or non-preferred hand, which changed around during the test trial. The results showed that there was bilateral transfer of learning for both anticipatory timing and force control. However, the positive transfer of force control was only significant in the preferred to non-preferred direction (Teixeira, 2000). This research shows that which hand is used during the practise and test phase can influence the transfer of learning and should thus be kept in mind for the experimental setup of the current study. Another study's result indicated that multiple-key chords are learned as one response action (Hazeltine et al., 2007). This configural learning points to the learning of body/hand postures, rather than the movement of each of the fingers that make up the chord.

Wifall et al. (2012) conducted another chording study in which they investigated the effect of similarity between chords on RT. They found that introducing a novel chord similar to one learned before led to a longer RT, as opposed to introducing a new, dissimilar chord. Similarity was measured as the number of pairs of key presses shared by two chords. Their experiment consisted of seven *dense* chords, chords with a high number of shared pairs, and seven *sparse* chords, chords with no shared pairs. The results showed that with practise, the difference of the RT on the sparse and dense chords got significantly larger, whereby the sparse chords had a shorter RT. This research indicates that similarity can interfere with skill acquisition (Wifall et al., 2012; Hazeltine & Aparicio, 2007). This is an important factor to consider for the current research, as the familiarity aspect of chords, as opposed to complete similarity, could thus lead to negative transfer.

For the current study, an experiment was designed to investigate to what extend spatial representations and body postures are involved in learning motor movements. Participants performed two 4-key chords in the practice phase of the experiment. In the test phase, mirror versions were introduced since they allow testing for spatial representations and hand postures. Spatial representations are tested in both the one hand mirror version and the two hand mirror version, as it is unclear whether bimanual chords are represented by a single spatial representation or by two hand specific representations. Hand postures are only tested in the two hand mirror version, as the hand posture previously executed by one hand is switched to the other hand.

Based on the literature on the topic, the hypothesis for this study is as follows: a significant difference was expected when comparing the RT on the mirror versions to the RT on novel chords. This is due to the positive transfer that was expected to occur when executing mirrored versions of learned chords. The positive transfer can then be explained by both the learning of hand postures and the learning of spatial representations in case of the two hand mirror version, and only by spatial representations in case of the one hand mirror version.

In accordance with this hypothesis, expectations are formulated. As described in the research design, it is expected that transfer occurs when the learned chord is mirrored. Therefore, the RT of these mirrored chords would be shorter than for the novel chords, but longer than the practised chords. If spatial representations are learned, both mirror versions are expected to have a shorter RT than the novel chords. If body postures are learned, only the two hand mirror version is expected to have a RT similar to that of the learned chords.

Methods

Participants

For this experiment, sixteen students voluntarily participated ($M_{\text{age}} = 21.9$, $SD_{\text{age}} = 1.7$). Most of the participants were recruited through the faculty of Behavioural, Management and Social Sciences (BMS) research system SONA. Others were personal contacts of the researchers. The participants were to adhere to the following criteria: (a) be within the age range of 18-35 years old, (b) have normal or corrected eyesight, (c) do not play a string- or key-instrument regularly, (d) do not play videogames on an expert or professional level, (e) do not smoke, (f) do not have consumed alcohol in the 24 hours prior to the experiment, and (g) did not participate in any other motor learning experiments. Three participants were replaced, one due to technical failure and two due to an extraordinary high error rate or extremely slow responses. The BMS ethics committee of the University of Twente approved this study (No. 230151). Participation in this study was rewarded with 3.5 credits in the university's credit system SONA.

Materials

The experiment was conducted in the BMS Laboratory of the University of Twente. In the lab, a separate experimental cubicle was booked for the duration of the experiment. The cubicle was equipped with a Dell OptiPlex 7050 7th Generation computer, a 24-inch LG monitor running with a 60 Hz refresh rate, and a Razer Huntsman V2 Tenkeyless keyboard. This special N-key rollover keyboard was chosen as it allows precise measurement of RT, even with several simultaneously pressed keys. To minimise the variation and potential distraction of incoming light, the blinds in the cubicle were lowered to three-quarters. The computer programme used for the experiment was designed using software E-Prime® 2.0 PST (Psychology Software Tools, 2023). To observe the participants and the stimulus display, a camera was installed in the cubicle.

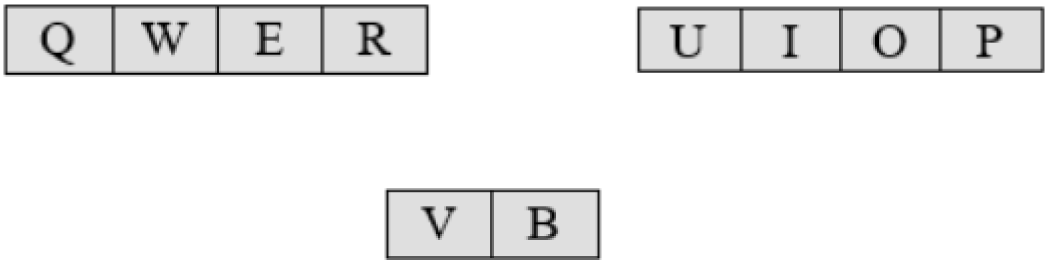
The participants signed an informed consent (Appendix A). Furthermore, each participant received an awareness questionnaire that was to be filled in between the break after the last practice block and the test block (Appendix B). This questionnaire asked participants to write down the two learned chords in terms of the pressed letters. Secondly, it asked how the participant remembered the chord: based on the combination of the letters, the position of the keys, position of the squares on the screen, pressing the keys in their mind, on the tabletop, or differently. Thirdly, it asked additional information about the participant's experience with playing the piano, other musical instruments, and sports. The participants filled out when they played, how many hours a week they play(ed), and for how many years they play(ed). This information was used to analyse potential correlations between these skills and the participant's RT.

Task

The first seven blocks included two different 4-key chords, using two fingers of each hand. The fingers of the left hand were placed on keys Q W E R and V. The fingers of the right hand were placed on keys B U I O P. This spatial layout can be found in Figure 1.

Figure 1

Image of the Used Keys for the Creation of the Chords



In Block 8, the participants were presented with four conditions: the two learned chords, as well as two novel chords, the mirrored versions of the learned chords across both hands, and the mirrored versions of the learned chords across one hand. Just like the learned chords, the novel chords were made up of two keys of each hand. The learned chords were counterbalanced across all participants to even out the potential effect of a specific chord and specific fingers.

Procedure

On the day of the experiment, the participants signed a consent form before participation (Appendix A). The researcher answered any questions they had and explicitly mentioned that the participant could withdraw from the study at any time, without having to give a reason.

The researcher explained that the set-up of the experiment consisted of 8 blocks in which the participant had to respond to stimuli shown on the computer screen. The first seven blocks contained 1120 practise trials in total, 560 per 4-key chord. The test block included 208 trials, divided over the four different conditions. Each condition thus had 52 trials, and as each condition consisted of two different 4-key chords there were 26 trials per chord. The participants were also told that every block had a small break in the middle and a longer, 4-minute break at the end. In that break, the participant was allowed to go outside of the room, stretch, or go to the bathroom. The researcher took away their phone to avoid any distractions. When the participant indicated that everything was clear, the researcher started the first block and went to the observation desk, from where the researcher used a camera to follow the progress of the participant. At the end of the 4-minute break, the researcher came into the room to manually start the next block and see how the participant was doing.

At the end of the seventh block and the 4-minute break, the participant received the awareness questionnaire on paper (Appendix B) and was asked to fill it out. Then, the researcher started the eighth block and explained to the participant that this block would be different than the ones before and that the participant should still try to react as quickly as possible, while keeping the error rate low.

After the eighth block was completed, the researcher asked the participant whether they had any questions about the experiment and if they were interested in receiving more information once the results were analysed. The researcher thanked the participant for their participation and granted them the SONA credits. On average, the experiment took 2.5 hours to complete.

Data Analysis

First, the collected data were screened in the statistical programme Rstudio operating on version 4.2.1. Packages Tidyverse, Ggplot2, readxl, afex, and emmeans were downloaded. The errors were transformed to the arcsine of the proportion errors per subject per block in the practice phase and per condition in the test phase. Thirdly, boxplots of the error proportions were created to analyse the distribution of errors in both the practise and test phase. To analyse the RT on the practise phase, boxplots were created as well in which the RT was on the y-axis and the block number on the x-axis.

To test the hypotheses, a one-way repeated measures ANOVA was performed on the data from the test phase (Block 8) with RT as the dependent variable and the four conditions (learned, mirrored across one hand, mirrored across both hands, and novel) as independent variable. The condition is a within-subject factor and participants were used as a random effect. This allowed analysis of the differences in RT between the types of chords, while keeping differences between RT of participants into account. The alpha level for all analyses was set on .05.

A planned comparison analysis using the emmeans package was conducted to compare the means of the *one hand mirror* and the *two hand mirror* with the *novel* and *practise* chord. This provided confidence intervals and p-values for each comparison.

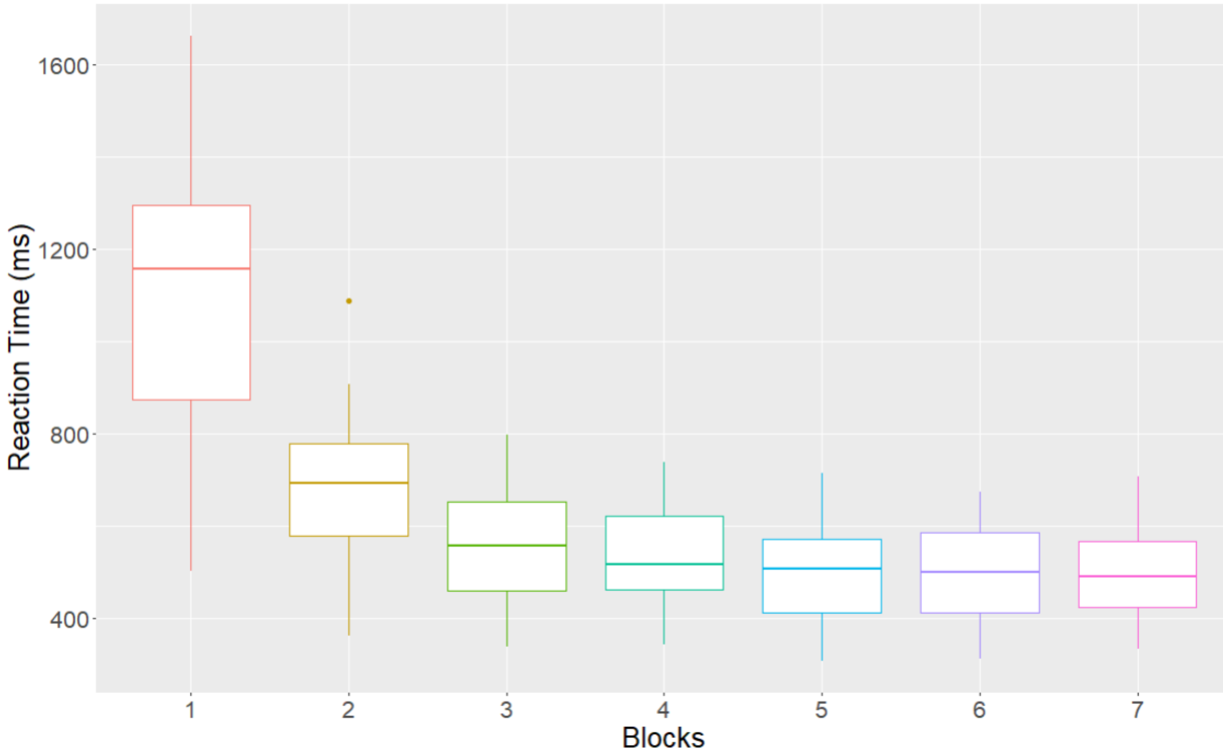
Results

The mean RT of correct trials per participant per block was calculated using the raw data, which consisted of the RT of the chords in each trial. For the test phase, the mean RT in the correct trails per participant per condition was used.

A visualisation of the RT per block in the practice phase can be found in Figure 1. The RT decreased as practise ensued. One participant had a significantly long RT in Block 2, which is visible as the outlier in the boxplot. However, as this occurred in a practice block, the data from this participant is kept in for the other analyses.

Figure 1

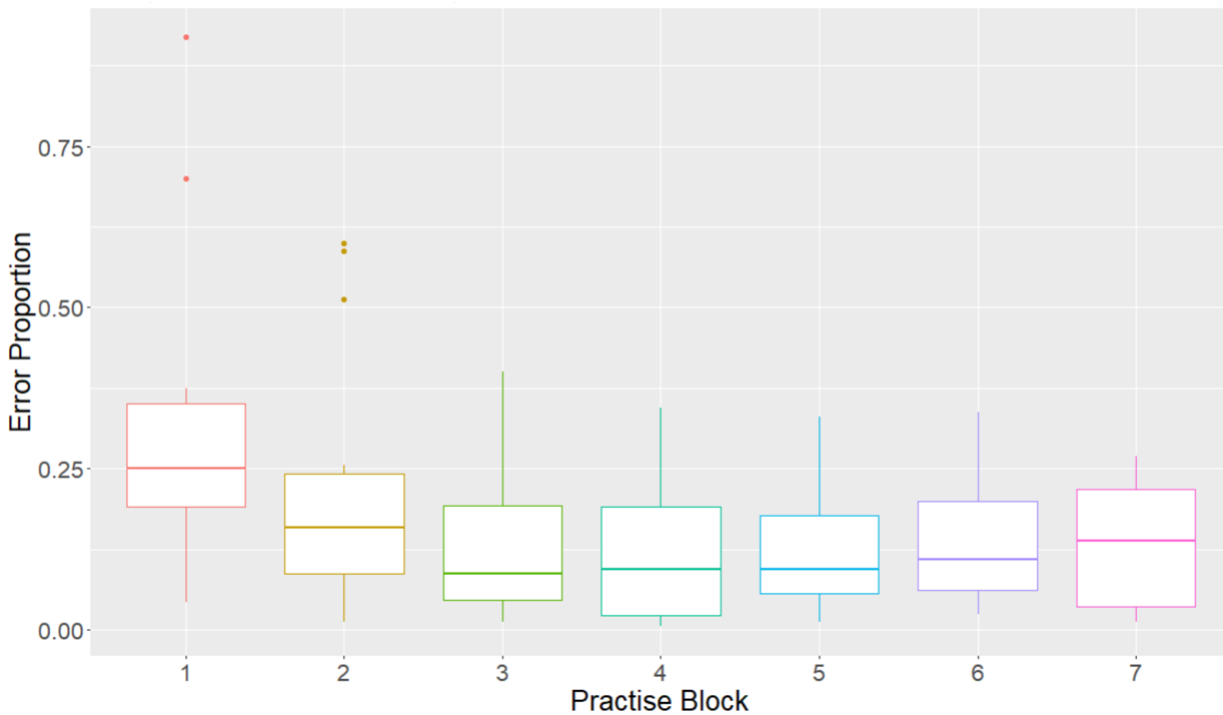
Boxplot of the RT in the Practice Blocks



Secondly, the errors in both the practice and test phase were converted into proportions. Boxplots per practise block were created (Figure 2). These boxplots show that the errors declined until Block 4, after which they increased again. In Block 1 and 2 are some outliers, but since this is the data from the practice phase it has no further consequences for the usability of those participants' data.

Figure 2

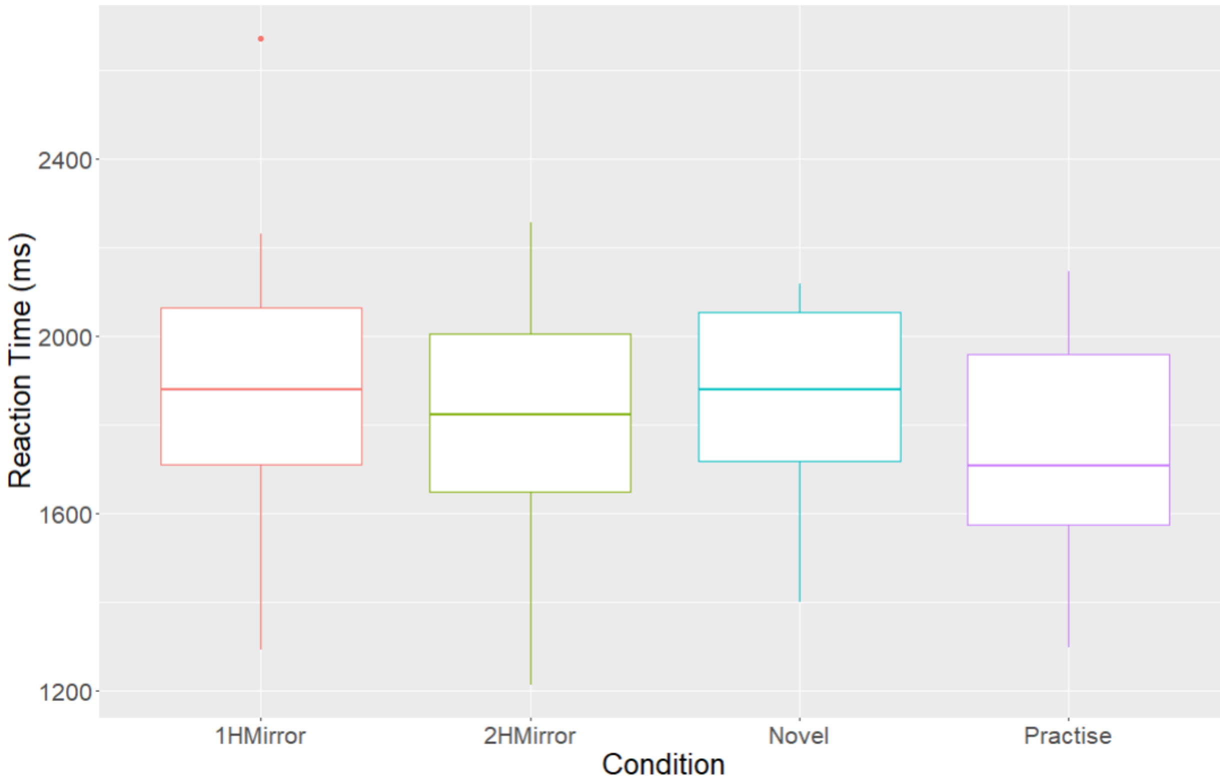
Boxplot of the Error Proportion in the Practise Blocks



Analysis of the RT in the test phase showed the following order from shortest to longest RT on the four conditions: *practised*, *two hand mirror*, *one hand mirror*, and *novel*. A one-way within-subject ANOVA was conducted to examine the effect of the four conditions in the test phase on the RT. Visualisations of the outcome of this ANOVA are presented in Figure 3. The main effect of the four conditions on RT was insignificant, $F(3, 45) = 1.850$, $p = .152$, $\eta^2 = .110$. Planned comparison tests revealed that only the group comparison *novel* and *practised* differed significantly, $t(15) = 3.886$, $p = .002$. The comparison of *one hand mirror* and *novel* is insignificant, $t(15) = .369$, $p = .717$. The comparison of *two hand mirror* and *novel* is also insignificant, $t(15) = -.786$, $p = .444$.

Figure 3

Boxplot of the RT per condition in the Test Phase

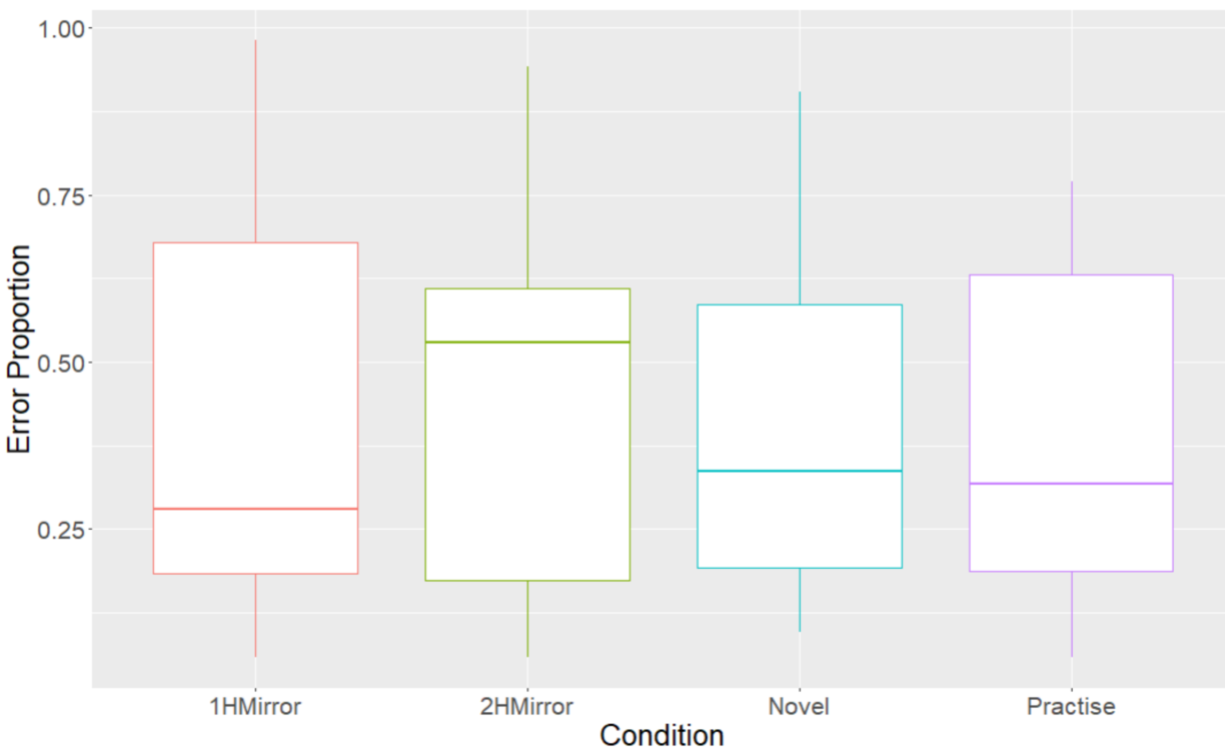


As can be seen from Figure 3, there is an outlier in RT for the *one hand mirror* condition. This data is a true anomaly, since there were no equipment issues or other distractions during the duration of this participant's experiment. When removing this participant from the dataset and conducting an ANOVA with the same design, the main effect of the four conditions on RT was significant, F(3, 42) = 3.112, p = .036, η^2 = .182. Planned comparison tests revealed that still only the group comparison *novel* and *practised* differed significantly, t(14) = 3.549, p = .003. The comparison of *one hand mirror* and *novel* is insignificant, t(14) = -.484, p = .636. The comparison of *two hand mirror* and *novel* is also insignificant, t(14) = .079, p = .938. It should be noted that removing this one participant from the counterbalanced design makes the data subject to incomplete balancing and possibly incorrect effects.

For the test phase, boxplots of the error proportion were created as well (Figure 4). The boxplots show that there was an increased variance in error proportion for the practised chord compared to the error proportion in the practice phase. It can be noted that the error rate is higher than at the end of the practise phase. This may be due to the introduction of the other three conditions, making the whole test phase more difficult and thus the learned chords more prone to errors as well.

Figure 4

Boxplot of the Error Proportion in the Different Conditions of the Test Phase



Awareness Questionnaire

Of the 32 chords presented amongst all 16 participants in the practise phase, 26 were remembered correctly. Most participants remembered the chords by the combination of the pressed letters or the position of the keys. Of all participants, five had played the piano more than 3 years ago, and three others play(ed) other instruments. Correlation coefficients and p-values were calculated for the correlations between RT and each of the *skill* questions on the questionnaire. These questions can be found in Appendix B. As seen in Table 1, none of the correlations are significant.

Table 1

Correlation Coefficient for RT and each Question on the Awareness Questionnaire

Correlation with RT	R-value	P-value
Piano – hours a week	.018	.947
Piano – total years played	.019	.945
Other instrument – hours a week	-.225	.402
Other instrument – total years played	-.186	.490
Sport (yes/no)	.264	.326
Sport – hours a week	.083	.760
Sport – total years played	.084	.756

Discussion

The current study investigated motor learning through analyses of transfer effects. Participants practised 4-key chords with fingers of both their left and right hand. After intense practice, the participants were presented with mirror versions of the learned chords. The planned comparison results show that there is a significant difference in the mean RT between the conditions *practised* and *novel*, indicating that learning did take place during the experiment. This is true for both the analysis with the outlier and without. Regardless, the hypothesis that there is positive transfer when mirroring the learned chords is rejected. The results show that there is no significant difference between the *one hand mirror* condition and both the *practise* and *novel* conditions. The same is seen for the *two hand mirror* condition. This is in line with research from Wifall et al. (2012) mentioned in the introduction. They found that partial similarity, as opposed to complete similarity or complete novelness, negatively impacts the RT. When presented with the mirror chords, the initial similarity might trigger the motor representations for the learned chord, whereafter the participant realises that this chord is slightly different and thus must choose another hand movement. This potential confusion takes time and might thus explain the insignificant difference between the mirror chords and the novel chords.

Even though there is no significant difference, the RT means of the four different conditions do lead to insights on transfer. It can be seen that the RT of the mirror chord over one hand is closer to the RT on the novel chord than the RT of the mirror chord over two hands. This suggests that the transfer is more positive for mirroring over two hands, as opposed to mirroring per hand. For mirroring over two hands, however, both a spatial representation and hand postures are expected to be involved. So, the shorter RT on the two hand mirror condition can still be explained by both the learning of spatial representation and the learning of hand postures. Therefore, considering this study setup, nothing can be said regarding which of the two is responsible for the observed transfer.

Limitations

The biggest limitation of the study at hand is the small number of participants. As said before, the means of the RT do point towards the hypothesised outcomes. So, it is expected that with an increased number of participants, this effect may become statistically significant.

Another limitation is the long attention span needed for the experiment. Several participants mentioned that they struggled with staying focussed on the task and noticed that this difficulty might have negatively affected their RT and error-rate. The participants got distracted or lost in their thoughts which caused them to not immediately notice the stimuli on the screen or make mistakes. On the other hand, this experiment simulates a learning process and that includes high levels of attention and frequent repetition. So, problems with attention spans might be inevitable. A third limitation is that due to miscommunication between the researchers, not every participant's phone was taken in during the duration of the experiment. Therefore, some participants spend the breaks on their phone. These distractions could have negatively impacted their learning process and thus altered the validity of the results.

A limitation of the research design is the keyboard that was used. Numerous participants indicated that the keys required quite some force to be totally pressed when compared to a laptop, which most participants are used to. Hence, even though participants pressed all correct keys, only some presses were forceful enough to be recognised by the system and those trials thus resulted in error messages. Although pressing with enough force is part of learning the chords, it could be the case that the amount of force required is so high that it negatively infers with the learning process. This notion about required force is in line with the findings of Li et al. (2001), explaining that force declines in multifinger and bimanual hand movements. Their results showed that force deficit, defined as "a drop in peak force in a multifinger task as compared to the sum of individual finger peak forces in single-finger tasks" (Li et al., 2001, p. 530), was positively correlated to the used number of fingers within the hand and in the other hand. The used keyboard might be perfectly fit for typing and other everyday usage, both activities where only one key is pressed at a time. However, problems arise when the keyboard is used for the current chording task involving simultaneous key presses. So, it is questionable whether the sensitivity benefit of the N-key rollover keyboard for simultaneous key presses outweighs this limitation of the amount of force required.

Directions for Future Research

Regardless of these limitations and the insignificant results, the current study contributes to building on our understanding of the intricate process of learning and executing motor movements. However, as the topic of investigating spatial representations versus hand postures in chording tasks is quite recent, more research is needed to deepen this knowledge. When this kind of research is repeated in the future, several things need to be changed. Firstly, as mentioned in the limitations, a redo of the current experiment would require more participants as this gives more precise results. Secondly, it might be insightful to use a keyboard that requires less force to detect key presses. Thirdly, experimenting with the similarity aspect of mirror chords could be beneficial to understand when mirroring facilitates positive transfer of learning and when it hinders positive transfer (Wifall et al., 2012). Lastly, another addition to investigate is to add sounds to the chords. Multiple participants mentioned they would like to hear some sound when pressing the keys to improve their attention span. This addition might also aid the learning process, as learning would then not only be based on visual stimuli, but also on auditory stimuli.

Conclusion

By experimenting with mirroring learned chords over one and both hands, this experimental study aimed to explore how motor learning operates in terms of spatial representations and hand postures. Rejecting the hypothesis, it was found that the transfer in motor learning is not as evident as expected in this research setup. It seems that a spatial representation is formed for both hands, rather than for both hands individually. However, hand postures could also be responsible for the learning process. Therefore, more research should be conducted to further investigate this aspect of motor learning and with that fill the existing literature gap on the topic.

References

Britannica. (2023). *Chord*. Retrieved from https://www.britannica.com/art/chord-music

Brooks, V. B. (1983). Motor Control: How Posture and Movements are Governed. *Physical Therapy, 63*(5), 664-673. DOI: 10.1093/ptj/63.5.664

Evarts, E. V. (1973). Motor cortex reflexes associated with learned movement. *Science, 179*(4072), 501-503. DOI: 10.1126/science.179.4072.501

Graziano, M. S. A., & Gross, C. G. (1993). A bimodal map of space: somatosensory receptive fields in the macaque putamen with corresponding visual receptive fields. *Experimental Brain Research, 97*(1), 96-109. DOI: 10.1007/BF00228820

Graziano, M. S. A., Reiss, L. A. J., & Gross, C. G. (1999). A neuronal representation of the location of nearby sounds. *Nature, 397*(6718), 428-430. DOI: 10.1038/17115

Hazeltine, E., & Aparicio, P. (2007). Configural Response Learning: The Acquisition of a Nonpredictive Motor Skill. *Journal of Experimental Psychology: Human Perception and Performance, 33*(6), 1451-1467. DOI: 10.1037/0096-1523.33.6.1451

Kantak, S. S., Stinear, J. W., Bunch, E. R., & Cohen, L. G. (2012). Rewiring the brain: potential role of the premotor cortex in motor control, learning, and recovery of function following brain injury. *Neurorehabilitation and neural repair, 26*(3), 282-292. DOI: 10.1177/1545968311420845

Li, S., Danion, F., & Latash, M. L. (2001). Bilateral deficit and symmetry in finger force production during two-hand multifinger tasks. *Experimental Brain Research, 141*, 530-540. DOI: 10.1007/s002210100893

Magill, R. A., & Anderson, D. I. (2018). *Motor Learning and Control: Concepts and Applications* (11th ed.). McGraw Hill.

Olson, D. R., & Bialystok, E. (1983). Spatial cognition: the structure and development of mental representations of spatial relations (1st ed.). Psychology Press. DOI: 10.4324/9781315802695

Psychology Software Tools. (2023). *E-Prime® | Psychology Software Tools*. Retrieved from https://www.pstnet.com/

Rosenbaum, D. A., Loukopoulos, L. D., Meulenbroek, R. G. J., Vaughan, J., & Engelbrecht, S. E. (1995). Planning reaches by evaluating stored postures. *Psychological review, 102*(1), 28–67. DOI: 10.1037/0033-295x.102.1.28

Rosenbaum, D. A., Meulenbroek, R. J., Vaughan, J., & Jansen, C. (2001). Posture-Based Motion Planning: Application to Grasping. *Psychological Review, 108*(4), 709-734. DOI: 10.1037/0033-295X.108.4.709

Seibel, R. (1962). Performance on a five-finger chord keyboard. *Journal of Applied Psychology, 46*(3), 165-169. DOI:10.1037/h0047948

Teixeira, L. A. (2000). Timing and Force Components in Bilateral Transfer of Learning. *Brain and Cognition, 44,* 455-469. DOI: 10.1006/brcg.1999.1205

Wifall, T., McMurray, B., & Hazeltine, E. (2012). Perceptual similarity affects the learning curve (but not necessarily learning). *Journal of Experimental Psychology: General, 143*(1), 312-331. DOI: 10.1037/a0030865

Yokoi, A., & Diedrichsen, J. (2019). Neural Organization of Hierarchical Motor Sequence Representations in the Human Neocortex. *Neuron*. DOI: 10.1016/j.neuron.2019.06.017

Appendix A

Informed Consent Form

University of Twente.
Participant Information Sheet

Research Project Title: **Investigating motor learning through uni- and bimanual chord practice on a keyboard**

This project has been approved by the University of Twente's Behavioural, Management, and Social Sciences (BMS) Ethics Committee Number 230151.

Researchers Contact Details:	**Supervisor Contact details**
Emile Zweistra Nynke Kreuwel	Prof. Dr. Ing. W. B. Verwey (Willem) Department of Cognitive Psychology and Ergonomics

Invitation to participate in the study:
you are invited to participate in our study about chord learning. Participation is entirely voluntary, and withdrawal from the study is possible at any given point in time during the study. Written consent to participate is required prior to the beginning of the experiment.

Purpose of the study:
The study is designed to assess the means by which chords are learned and developed in cognition.

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 play string- or keyboard instruments on a professional level or are a professional gamer (meaning you have been paid)
- You do not smoke
- You have not consumed alcohol in the past 24 hours
- You are not physically injured
- You have normal or corrected eyesight

- You do not have any learning disabilities, diagnosed mental health issues or ny neurological disorders (such as Alzheimer's, Parkinson's, Stroke, Multiple Sclerosis, Brain tumour, Physical Brain injuries, Seizures or previous concussion/coma)
- You have not previously taken part in any motor learning experiments **in the BMS Lab via SONA**
- You are comfortable attending **1 session of data collecting for up to 3 hours**
- You are feeling generally well, and do not experience any COVID-19 symptoms

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

Requirements:
You must participate in the research study involving attending a laboratory session for up to 3 hours for completion and 3.5 SONA credits.

Lab session (~3 hours):
The participants will be introduced and demonstrated a chording task requiring them to use their hands to respond. Participants are required to perform 7 practise blocks in which they learn different chords. At the end point of each block, participants will have a 4-minute break in which they may move around or leave the room. After the practise blocks, a test block is administered. After completion, a questionnaire is required to be filled out concerning their knowledge of the chords and space for comments regarding the research. Finally, participants will be debriefed about the goal of the experimenta 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 they have indicated interest.

Consent Form for: Investigating motor learning through uni- and bimanual chord practise on a keyboard

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes **Taking part in the study**	**Yes**	**No**
I have read and understood the study information dated [______________] (DD/MM/YYYY), or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	◯	◯
I consent voluntarily to participate in this study and understand that I can refuse to answer questions and withdraw from the study at any time, without having to give a reason.	◯	◯
I understand that participating in the study involves a reaction time task in which I have to press buttons in response to the stimuli on the computer screen.	◯	◯
Use of information in the study		
I understand that the information I provide will be used for student reports and perhaps for a journal publication or conference report.	◯	◯
I understand that personal information collected about me that can identify me, such as my name, will not be shared beyond the study team.	◯	◯
Future use and reuse of the information by others		
I give permission for the reaction time data that I provide to be anonymously archived in the repository of the Open Science Framework so it can be used for future research and learning.	◯	◯

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.

Name of researcher	Signature	Date

Contact information for questions about your rights as a research participant
If you have any questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee of the Faculty of Behavioural, Management, and Social sciences at the University of Twente by ethicscommitte-bms@utwente.nl

Appendix B

Awareness Questionnaire

Participant Number ____

Age ____

Right or left handed ____

Do you smoke? ____

Did you drink alcohol in the last 24 hours? ______________________________

In this experiment you reacted by pressing keys after perceiving a stimulus light. There were a number of different combinations, while other combinations did not occur. Are you able to write down the combinations you have been practising? (using the letters QWER – VB – UIOP)?

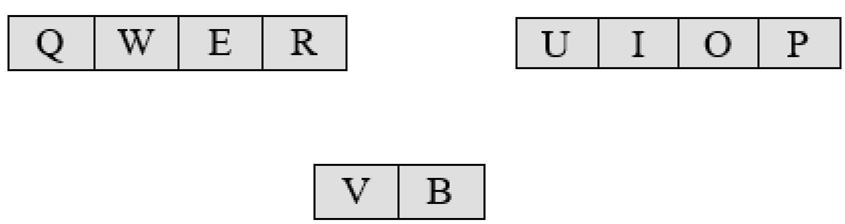


Image of the keys on the keyboard

1) What did you do to determine on the previous page of this survey the keys you pressed? (you may circle more than 1 alternative).

a) I remembered the combination of the letters.
b) I remembered the positions of the keys.

c) I remembered the <u>positions</u> of the squares on the screen.
d) I pressed the keys in my mind
e) I pressed the keys on the tabletop
f) Differently, namely:

Below, a number of activities is mentioned. Do you perform these activities? If yes, how long was it ago, and how long have you done this (check 1 alternative per row). Indicate no at the end of the row if you have never done this activity

a) Do you play **video games**?

When?	I still play	Until 3 years ago	More than 3 years ago

I play(ed)	< 1 hour a week	1-7 hours per week	>7 hours a week

Totally I played …	< 1 year	1-5 years	> 5 years

b) Do you play **the piano?**

When?	I still play	Until 3 years ago	More than 3 years ago

I play(ed)	< 1 hour a week	1-7 hours per week	>7 hours a week

Totally I played …	< 1 year	1-5 years	> 5 years

c) Do you play another **musical instrument**(s), if yes, which one(s)?

When?	I still play	Until 3 years ago	More than 3 years ago

I play(ed)	< 1 hour a week	1-7 hours per week	>7 hours a week

Totally I played …	< 1 year	1-5 years	> 5 years

d) Do you play any **sport(s)**, and which**?** (in the case of several sports, please answer for each sport separately)

When?	I still play	Until 3 years ago	More than 3 years ago

I play(ed)	< 1 hour a week	1-7 hours per week	>7 hours a week

Totally I played …	< 1 year	1-5 years	> 5 years

e) Do you **stutter?**

No	A little	A fair amount	Severely

f) Do you have **dyslexia?**

No	A little	A fair amount	Severely

3) Do you have any remarks about the experiment?

Appendix C

Rscript

```
## NEAT RSCRIPT ##
## Set working directory ##
## install packages ##
install.packages(c("ggplot2", "ggpubr", "tidyverse", "broom", "AICcmodavg"))
install.packages("readxl")
install.packages("afex")
install.packages("emmeans")

## load packages ##
library (tidyverse)
library (ggplot2)
library(ggpubr)
library(broom)
library(AICcmodavg)
library(readxl)
library(afex)
library(emmeans)

## import data ##
Data_Practise_RT <- read_excel("Data blok17 RT.xlsx")
Data_Practise_error <- read_excel("Data blok17 error.xlsx")
Data_Test_RT <- read_excel("Data blok8 RT.xlsx")
Data_Test_error <- read_excel("Data blok8 error.xlsx")

## adjust data ##
Data_Practise_RT <- Data_Practise_RT[, -which(names(Data_Practise_RT) == "...2")]
Data_Practise_RT <- Data_Practise_RT[-c(1, 2),]
Data_Practise_RT <- Data_Practise_RT %>%
  rename(Subject = ...1)
Data_Practise_RT$Subject <- as.character(Data_Practise_RT$Subject)
Data_Practise_error <- Data_Practise_error[, -which(names(Data_Practise_error) == "...2")]
Data_Practise_error$Subject <- as.character(Data_Practise_error$Subject)
Data_Practise_error[, c("B1", "B2", "B3", "B4", "B5", "B6", "B7")] <-
  lapply(Data_Practise_error[, c("B1", "B2", "B3", "B4", "B5", "B6", "B7")], as.numeric)
Data_Test_RT <- Data_Test_RT[, -which(names(Data_Test_RT) == "...2")]
Data_Test_RT <- Data_Test_RT[-c(1, 2),]
Data_Test_RT <- Data_Test_RT %>%
  rename("1HMirror" = ...3, "2HMirror" = ...4, Novel = ...5, Practise = ...6)
Data_Test_RT$`1HMirror` <- as.numeric(Data_Test_RT$`1HMirror`)
Data_Test_RT$`2Hmirror` <- as.numeric(Data_Test_RT$`2Hmirror`)
Data_Test_RT$Novel <- as.numeric(Data_Test_RT$Novel)
Data_Test_RT$Practise <- as.numeric(Data_Test_RT$Practise)
Data_Test_error <- Data_Test_error[, -which(names(Data_Test_error) == "...2")]
Data_Test_error[, c("1HMirror", "2HMirror", "Novel", "Pract")] <-
```

```
  lapply(Data_Test_error[, c("1HMirror", "2HMirror", "Novel", "Pract")], as.numeric)
Data_Test_error$Subject <- as.character(Data_Test_error$Subject)

## check data ##
summary(Data_Practise_RT)
summary(Data_Practise_error)
summary(Data_Test_RT)
summary(Data_Test_error)

## Analysing the ERRORS IN THE PRACTISE PHASE with boxplots ##
ErrorProportionPractise <- Data_Practise_error %>% select(B1:B7)
ErrorProportionPractise <- ErrorProportionPractise %>%
  rename("1" = B1, "2" = B2, "3" = B3, "4" = B4, "5" = B5, "6" = B6, "7" = B7)

LongErrorProportionPractise <- pivot_longer(ErrorProportionPractise, cols = c("1", "2", "3", "4", "5",
"6",  "7"), names_to = "Blocks", values_to = "value")

boxploterrorpractise <- ggplot(LongErrorProportionPractise, aes(x = Blocks, y = value, color = Blocks))
+ geom_boxplot() + labs(x = "Practise Block", y =  "Error Proportion", title = "Boxplot of the Error
Proportion in the Practise Blocks")
boxploterrorpractise + theme(text = element_text(size = 22))

## Analysing the ERRORS IN THE TEST PHASE with boxplots ##
ErrorProportionTest <- Data_Test_error %>% select("1HMirror":"Pract")
ErrorProportionTest$`1HMirror` <- as.numeric(ErrorProportionTest$`1HMirror`)
ErrorProportionTest$`2HMirror` <- as.numeric(ErrorProportionTest$`2HMirror`)
ErrorProportionTest$Novel <- as.numeric(ErrorProportionTest$Novel)
ErrorProportionTest$Pract <- as.numeric(ErrorProportionTest$Pract)
ErrorProportionTest <- ErrorProportionTest %>%
  rename("Practise" = Pract)

LongErrorProportionTest <- pivot_longer(ErrorProportionTest, cols = c("1HMirror", "2HMirror",
"Novel", "Practise"), names_to = "Conditions", values_to = "Value")
boxploterrortest <- ggplot(LongErrorProportionTest, aes(x = Conditions, y = Value, color = Conditions))
+  geom_boxplot() + labs(x = "Condition", y =  "Error Proportion", title = "Boxplot of the Error
Proportion in the Different Conditions of the Test Phase")
boxploterrortest + theme(text = element_text(size = 22))

## Analysing the RT in the PRACTISE PHASE ##
Data_Practise_RT$B1 <- as.numeric(Data_Practise_RT$B1)
Data_Practise_RT$B3 <- as.numeric(Data_Practise_RT$B3)
Data_Practise_RT <- Data_Practise_RT %>%
  rename("1" = B1, "2" = B2, "3" = B3, "4" = B4, "5" = B5, "6" = B6, "7" = B7)
LongRTPractise <- pivot_longer(Data_Practise_RT, cols = c("1":"7"), names_to = "Blocks", values_to =
"Reaction Time (ms)")
boxplotRTpractise <- LongRTPractise %>%
  ggplot(aes(x = Blocks, y = `Reaction Time (ms)`, color = Blocks)) +
  geom_boxplot()

boxplotRTpractise + theme(text = element_text(size = 22)
```

```
## Analysing the RT in the TEST PHASE ##
Data_Test_RT$`2HMirror` <- as.numeric(Data_Test_RT$`2HMirror`)
Data_Test_RT$Novel <- as.numeric(Data_Test_RT$Novel)
Data_Test_RT$Practise <- as.numeric(Data_Test_RT$Practise)
LongRTTest <- pivot_longer(Data_Test_RT, cols = c("1HMirror", "2HMirror", "Novel", "Practise"),
names_to = "Condition", values_to = "Reaction Time (ms)")
boxplotRTTest <- LongRTTest %>%
  ggplot(aes(x = Condition, y = `Reaction Time (ms)`, color = Condition)) +
  geom_boxplot()
boxplotRTTest + theme(text = element_text(size = 22))

## conduct ANOVA ##
Data_Test_RT$`2HMirror` <- as.numeric(Data_Test_RT$`2HMirror`)
Data_Test_RT$Novel <- as.numeric(Data_Test_RT$Novel)
Data_Test_RT$Practise <- as.numeric(Data_Test_RT$Practise)
Long_Data_Test_RT <- pivot_longer(Data_Test_RT, cols = c("1HMirror", "2HMirror", "Novel",
"Practise"), names_to = "Condition", values_to = "Value")
AnovaTest2 <- aov_car(Value ~ Condition + Error(Subject/Condition), data = Long_Data_Test_RT)
summary(AnovaTest2)
boxplot(Value ~ Condition, data = Long_Data_Test_RT, col = "green", notch = FALSE) +
  theme(text = element_text(size = 22))

## GLM for significance between conditions ##
emm <- emmeans(AnovaTest2, ~ Condition)
pairwise <- contrast(emm, method = "pairwise", adjust = "none")
summary(pairwise, infer = TRUE)

# ANOVA Test met participant 2 eruit
Data_Test_RT2 <- Data_Test_RT[-c(2),]
Data_Test_RT2$`2HMirror` <- as.numeric(Data_Test_RT2$`2HMirror`)
Data_Test_RT2$Novel <- as.numeric(Data_Test_RT2$Novel)
Data_Test_RT2$Practise <- as.numeric(Data_Test_RT2$Practise)
Long_Data_Test_RT2 <- pivot_longer(Data_Test_RT2, cols = c("1HMirror", "2HMirror", "Novel",
"Practise"), names_to = "Condition", values_to = "Value")
AnovaTest2.2 <- aov_car(Value ~ Condition + Error(Subject/Condition), data = Long_Data_Test_RT2)
summary(AnovaTest2.2)
boxplot(Value ~ Condition, data = Long_Data_Test_RT2, col = "maroon", notch = TRUE)
summary(Data_Test_RT2)

## GLM for significance between conditions ##
emm <- emmeans(AnovaTest2.2, ~ Condition)
pairwise <- contrast(emm, method = "pairwise", adjust = "none")
summary(pairwise, infer = TRUE)

## skills en RT test ##
Awareness <- read_excel("Awareness en RT2.xlsx")
Awareness$`Piano hours` <- as.numeric(as.character(Awareness$`Piano hours`))
Awareness$`Piano years` <- as.numeric(as.character(Awareness$`Piano years`))
Awareness$`Instrument hours` <- as.numeric(as.character(Awareness$`Instrument hours`))
Awareness$`Instrument years` <- as.numeric(as.character(Awareness$`Instrument years`))
```

```
Awareness$`Sport now` <- as.numeric(as.character(Awareness$`Sport now`))
Awareness$`Sport hours` <- as.numeric(as.character(Awareness$`Sport hours`))
Awareness$`Sport years` <- as.numeric(as.character(Awareness$`Sport years`))
Awareness$`Reaction Time` <- as.numeric(as.character(Awareness$`Reaction Time`))
Correlations <-   Awareness[c("Reaction Time", "Piano hours", "Piano years", "Instrument hours",
"Instrument years", "Sport now", "Sport hours", "Sport years")]
correlation_matrix <- cor(Correlations)
print(correlation_matrix)
Sport_years <- cor.test(Awareness$`Reaction Time`, Awareness$`Sport years` , method = "pearson")
print(paste("Correlation coefficient:", Sport_years$estimate))
print(paste("p-value:", Sport_years$p.value))
```