Bachelorthesis

The effects of task complexity on motor preparation in a typewriting task.

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Abstract

The learning of a movement skill usually progresses from a more attentive phase to a more automated phase, reducing the strain on cognitive capacity. Previous studies have pointed out that different cognitive processes may underlie these different phases of motor skill acquisition and may even be present during motor preparation. Various forms of task complexity seem to influence event-related potentials such as the contingent negative variation. In this study, the electroencephalogram was recorded of participants who copy typed words which were manipulated in familiarity (Dutch and nonsense words) and length (five and seven letter words). The most profound result of the present study was the absence of a central CNV and a more pronounced CNV at parietal sites and an increased negative CNV amplitude for unfamiliar words. This is not in line with results of studies who use classical discrete sequence production tasks. These results may implicate that in highly developed motor skills, motor preparation takes place on a higher cognitive level and in more parietal regions.

1. Introduction

During our lifetime we learn all kinds of skills to help us interact with the world. Most of these skills are not learned over night and take some time to master. Learning to play a musical instrument or learning to drive a car is a process in which the learner performs increasingly better with practice. In the beginning of the learning process, every single step needs to be attended individually. A novice piano player will need his full attention to place every single finger of his hand on the piano keyboard in order to play a chord. Eventually, a more advanced player will put his fingers in the correct position without having to think about it. The ability to learn these skills allows us to perform complex tasks, without having to focus all our attention towards it. Because the use of these skills make up an important part of our lives, it is vital to have a good understanding of how these cognitive processes work. This study will explore the effects of task complexity on the cognitive load in such skills.

1.1 Theoretical framework

Fitts and Posner (1967) have suggested a three stage model on the acquisition of skills. Their theory describes how a novice starts at a cognitive stage (1), where a lot of attention is needed to perform the task at hand. Eventually, through practice, the novice will become enter the associative stage (2) and is able to make subtle adjustments to execute the task more smoothly. Eventually, the actor will end up in an automatic stage (3), where little cognitive resources are required to perform the task quick and accurate. Cognitive science has advanced rapidly since the days of Fitts and Posner and numerous studies have since looked into the acquisition of motor skills and new evidence has lead to new insights (Gerloff, Corwell, Chen, Hallett, & Cohen, 1997; Jenkins, Brooks, Frackowiak, & Passingham, 1994; Nattkemper & Ziessler, 2004). For example, studies have suggested that the different phases of skill acquisition may also be represented by different cognitive mechanisms (Doyon & Benali, 2005; de Lange, Hagoort, & Toni, 2005).

One well known mechanism which may help to explain the differences in the acquisition of motor skills is known as motor chunking (Verwey, 2001). According to this concept, sequences of small, individual movement actions that are frequently executed after another (such as pressing down the clutch with one foot and reaching for the gear lever with your arm to manually shift gear in a car) are grouped together to form one cognitive motor chunk. By grouping the individual movement actions, the entire movement can be processed as a whole. This reduces the cognitive load and makes it easier to perform these movements (Koch, 2007).

A promising approach to study the effects of motor preparation and motor chunking is electroencephalography (EEG) as can be seen in recent studies (Dirnberger et al., 2000; Gómez, Flores, & Ledesma, 2007; Leuthold & Schröter, 2011). By studying several event related potentials (ERPs) derived from the EEG, new insights have been given concerning the role of motor chunking. One of the ERPs of particular interest is the contingent negative variation (CNV) which has been strongly identified with motor preparation in the past. The CNV is a prolonged negative potential which can be measured between the first warning stimulus and the imperative stimulus. It is most strongly measured in the central-parietal area and particularly on the Cz and Pz electrode (Leynes, Allen, & Marsh, 1998). Although there is very little doubt that the CNV is closely related to motor preparation and that task complexity is reflected in it, it is still uncertain which exact cognitive processes are represented in the CNV (van Boxtel & Brunia, 1994; Cui et al., 2000; Leynes et al., 1998).

Recent research has been conducted on the effects of a tasks complexity and the CNV. There are various factors that contribute to the complexity or difficulty of a task. Cui et al. (2000) have looked into the physical complexity of a task e.g. it is physically more easy to reach your index finger with your thumb compared to reaching your little finger with your thumb. They found a greater CNV amplitude before physically complex tasks and a smaller CNV amplitude before physically easy tasks and have suggested that the CNV reflects the level of preprogramming of the movement. In a study by Schröter & Leuthold (2009), the task complexity was varied by moderating the length of the sequences that had to be performed. They found an increased negative CNV before the execution of a task with multiple key presses compared to a task involving a single key press, suggesting that it may reflect the number of prepared key presses. De Kleine & van der Lubbe (2011) have examined a completely different form of task complexity: the familiarity of a task. They found an increased negative CNV when participants performed movement sequences which were unknown to them compared to sequences which they had familiarized themselves with (trained) before hand. The three before mentioned studies have shown that various forms of task complexity influence the amplitude of the CNV.

The first two goals of the present study were to further investigate the increased CNV amplitude for increased task complexity, in particular the aspects of task familiarity (henceforth defined as the "task familiarity dimension") and the aspect of stimulus length (hereafter defined as the "stimulus length dimension"). Additionally, a third, exploratory goal was set for this study concerning the nature of the given task. Most previous studies who have looked into familiarity and sequence length, such as the studies by Schröter & Leuthold and De Kleine & Van der Lubbe, have all used tasks which were highly similar to the Discrete Sequence Production task (DSP). Participants in DSP experiments are asked to respond to a series of key-specific stimuli which appear to them in a consistent and discrete order. Because these sequences of stimuli and responses are always identical, the participants will be able to perform the task faster and more accurate after a while because of a learning effect. The hierarchical nature of the sequences and the fact that the stimuli are easy to manipulate make the DSP task a useful task to study this learning behavior. However, one important difficulty arises with the use of the classical DSP task. In order to keep high experimental control and optimal conditions for EEG measurement, most tasks are very simplified and stripped down to a meaningless sequence of key presses. Often, these simple tasks hardly resemble everyday life tasks and therefore generalization to everyday life may pose difficulties. In order to bridge this gap between the laboratory and reality, this study has looked into a task which is a part of our everyday life and therefore more natural, but at the same time shares the practical aspects of the classical DSP tasks, namely typewriting.

In the past, Salthouse (1986) has pointed out that there are three reasons why typewriting tasks are particularly practical for the analysis of skilled behavior. The first reason is the availability of a large number of individuals with considerable typewriting skill because typewriting is an important part of many modern jobs. Secondly, by using a computer, every keystroke can easily and discretely be recorded. And thirdly because typewriting encompasses the cognitively complex perceptual and motor processes. However, using a typewriting task instead of the classical DSP task comes with its own limitations. Because the typewriting task relies on words to be copied, there is a certain linguistic element involved. The reading, comprehension and typing of words is a highly automated process which may also influence motor processes (Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005) and therefore the CNV. Because of this linguistic element, it may be difficult to compare the results of this study with the results of previous studies who used non-linguistic stimuli. There also may be a fundamental difference between the reproduction of pre-learned sequences compared to applying a more all-round, generic motor skill such as typewriting which developed through years of experience (Gordon, Lee, Flament, Ugurbil, & Ebner, 1998). For example, typewriting is a more robust skill which facilitates the typing of all kinds of different words, while the learning of a sequence only facilitates the execution of that individual sequence.

1.2 Proposed experiment

In order to put the differences in task complexity (task familiarity and stimulus length dimensions) to the test, the following experiment was designed. The task consisted of a go/nogo task in which the participants had to copy type words which were presented on a screen using a regular keyboard. To manipulate the familiarity aspect of task complexity, a mix of two types of words was presented. Dutch words which frequently occur in the Dutch language as familiar words and on the other hand pronounceable nonsense words as unfamiliar words (similar to Wiggs & Martin, 1994). Because all participants were Dutch native speakers and were advanced typists, it was assumed that the they would be able to use visual and or motor chunks (already available to them through previous typing experience) while typing the familiar Dutch words, but not so in the unfamiliar nonsense words condition. The ability to make use of these motor chunks for the words in the familiar condition would reduce the cognitive load and according to the results by De Kleine & Van der Lubbe (2011), reduce the amplitude in CNV. It was therefore hypothesized that mean CNV amplitudes would reveal increased negativity for unfamiliar words. Also, it was expected that familiar words would be executed faster compared to unfamiliar words. To test the differences in the stimulus length dimension, a mix of long, seven letter words and short, five letter words was used. The longer words were expected to be more demanding on the cognitive capacity compared to the smaller words. Based on the previous findings by Schröter & Leuthold (2009), it was hypothesized that the CNV would reveal increased negativity for long words. Also, it was predicted that the overall execution speed of the short words would be faster compared to the longer words. It is not unlikely that the effect of familiarity was increased if the words were longer, therefore an interaction effect was expected.

1.3 Thesis goals

In summary, the goal of the present study was threefold. The first goal was to analyze the effect of stimulus familiarity on the CNV. The second goal was to study the effect of stimulus length on the CNV. Finally, the third goal was to determine if similar CNV characteristics could be measured during more realistic tasks compared to the stripped down sequence reproduction tasks. This goal however, had an explorative function and was not tested in an experimental design.

2. Methods

2.1 Participants

Sixteen students participated in the experiment (nine males and seven females), aged 18-22 years (mean: 20.06 years) from the University of Twente. Two participants were left-handed and 14 right-handed, measured by the Annett Handedness Inventory by (Annett, 1970). The mean typing speed of the participants was 63,37 words per minute, measured by the continuous typing of a Dutch text for two minutes, using Typingmaster version 6.30 (TypingMaster Inc, 2005; e.g. Liang, Hwang, & Chang, 2008) . Participants were rewarded course credits for participating. All participants gave written informed consent and reported normal or corrected-to-normal vision. The study was approved by the local ethics committee of the Faculty of Behavioral Sciences of the University of Twente and was performed according to the Declaration of Helsinki.

2.2 Stimuli and tasks

Participants were asked to place their fingers on the keyboard in front of the computer screen on the home row. One trial in the experiment consisted of four different stages (also see Fig. 1). The first stage was a unique word which corresponded with one of the four conditions (Short-Dutch words, Long-Dutch words, Short-nonsense words and Long-nonsense words) in the centre of the screen for 3500ms. It served as the informative cue. During the second stage, a neutral, gray fixation cross was presented at the centre of the screen which functioned as the preparation interval. After 2000ms the neutral fixation cross would either change into a red or a blue cross (third stage). The changing color served as the imperative stimulus. If a blue cross appeared, the “go” procedure was initiated and the participant would type in the word which was presented at the first stage. During the typing of the word, the fixation cross would remain visible on screen and participants were instructed to remain fixated. Visual feedback on which keys were pressed was not shown during the typing. When the last key (i.e. the fifth or the seventh) of a word sequence was pressed, feedback on the performance of the task was given by showing the Dutch word “goed” if the response was correct or “fout” if the response was incorrect (Dutch equivalents of “correct” and “incorrect”). The red fixation cross indicated the initiation of the “nogo” condition, in which case the participants were not to give a response. If after 3000ms no response was given the word “goed” was shown as feedback for a correct response. If a key was pressed within the 3000ms interval, the word “fout” was shown, indicating a wrong response. The visual feedback “goed” or “fout” was presented for 1500ms. After this, the trial was ended and a new trial was presented immediately afterwards. A total of 200 trials were offered to each participant with ten percent of the trials being “nogo” trials. The order in which the trials were presented was randomized for each participant. A thirty second break was offered after every twenty trials which allowed the participant to relax. Fig. 1 shows a schematic timeline of the order of presentation of the stimuli.

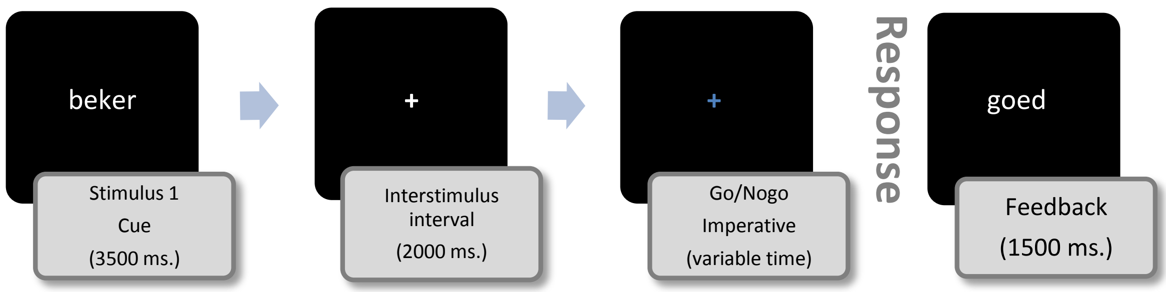


Fig. 1 Schematic overview of the task.

Two dimensions were studied in this experiment: length and familiarity. Length would be controlled by using short five letter words and long seven letter words. Familiarity was controlled by using Dutch words and nonsense words. This resulted in four experimental conditions: Short-Dutch words, Short-nonsense words, Long-Dutch words and Long-nonsense words. Each condition was represented by a wordlist containing 50 unique words. Both short and long Dutch words were selected from a list of frequently used Dutch words acquired from the Dutch institute of lexicology (INL). Verbs and words with strong action related semantics (such as “hammer”) were not selected because of possible motor cortex activation during reading of such words (Hauk, Johnsrude, & Pulvermüller, 2004). To create the list of Non-sense words, three measures were taken into consideration to make sure that the words had similar physical properties. First, all nonsense words used the exact same letters as their Dutch counterparts. This was done to counterbalance for the physical difficulty of the placement of the keys (e.g. the “t” and the “b” are particularly difficult to reach on a qwerty keyboard). Second, all nonsense words would have to be pronounceable in Dutch. Previous studies have shown that pronounceable words are easier to reproduce compared to unpronounceable words (Gibson, Pick, Osser, & Hammond, 1962), therefore all words used in this study were pronounceable in this study to counterbalance this effect. The third measure ensured that if the Dutch word from which a nonsense word was derived contained a double letter combination, the nonsense word also used the same double letter combination (e.g. “apple” became “leppa”). This was done to counterbalance the execution speed effects of a double key press on the overall reaction time.

2.3 Procedure

After participants had given their written informed consent, two small tests were conducted before the actual experiment started. The first was the Annett Handedness Inventory (Annett, 1970) to assess the handedness of the participants. The second was a typing ability test to assess the participants typewriting speed. The test involved the copy typing of a text for two minutes, after which the words per minute were calculated and the percentage of typing errors. The same text was used for all participants. Participants who scored below forty words per minute were considered unfit for the experiment and their data were not used for analysis. After these tests, the EEG equipment was configured and the electrodes were applied. Before the start of the experiment, the participants were given instructions on how to respond during the experiment and to work as fast and accurate as possible. After the 200 trials were completed, the experiment was ended.

2.4 Recording and data processing

The experiment was ran on a Pentium 4 personal computer. The presentation of the stimuli, registration of behavioral data (key presses) and production of external triggers were regulated by experimentation software E-prime, version 2.0. Input for the behavioral data was a QWERTY keyboard. The stimuli were presented using a CRT monitor placed on eye level, approximately 40 cm in front of the participant. For the EEG recording, seventeen electrodes were used in total (FPz, AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz, F3, F4, C3, C4, P3, P4, PO7, PO8). A horizontal and vertical electro-oculogram (EOG) were recorded using bipolar EOG electrodes. The horizontal EOG electrodes were placed on the outer canthi of both eyes. The vertical EOG was placed above and below the left eye. The signal from the EOG and EEG electrodes were amplified using a Quick-Amp amplifier (72 channels, DC) and recorded with Brain Vision Recorder (version 1.05) software. Electrode impedance was kept below 5 kOhm.

The EEG and EOG data were sampled at a rate of 500 Hz. Measured activity was digitally filtered online (low-pass 140 Hz, DC).

2.5 Data analysis

For statistical analyses, Greenhouse-Geisser epsilon correction was applied whenever appropriate. In total, two participants were left out from the final analysis. One participant was removed from the data set because the session was not entirely recorded. The other participant was excluded because of an insufficient score on the typing ability test (34 words per minute, while the threshold for analysis was set at 40 words per minute). It was assumed that motor preparation was similar in case of correct and incorrect responses, therefore EEG analysis was performed on all data (correct and incorrect responses without artifacts), similar to De Kleine and Van der Lubbe (2011). After visual inspection of the data, a new baseline was calculated and set at 1600 and 1500 before the go/nogo signal which is comparable to De Kleine & Van der Lubbe (2011). For statistical analysis, trials with artifacts (an amplitude difference larger than 100 µV within 50 ms) and out of range values (values larger than +/- 250 µV for prefrontal electrodes, +/- 200 µV for frontal electrodes, +/- 150 µV for central electrodes, and +/- 100 µV for parietal electrodes) were excluded from further analyses. Next, EEG was corrected for EOG artifacts by the Gratton, Coles, and Donchin (1983) procedure. Finally, a low-pass filter with a cut-off at 16 Hz was applied to average event-related brain potentials of individual participants.

2.6 Reaction time parameters

Reaction time (RT) analyses were only performed on the correctly executed go trials. This was done because if one key press was incorrect, usually the following key presses were delayed because the participant realized the mistake. Therefore those RT values did not reflect the true nature of the task. A total of four separate reaction time analyses were performed. The first RT test was the mean RT for the first key press and was defined as the interval between the go signal and the first key press. A repeated-measures ANOVA was used with task familiarity (2) and stimulus length (2) as within-subject factors. A second analysis was performed on the averaged inter-key intervals (IKI; e.g.(Liang et al., 2008). A simple mean RT analysis would not suffice as mean RT's for short words would always be higher compared to the long words. This is because the RT for the first key press is always higher compared to the following key presses in the sequences and this has a higher impact on the mean RT for short words compared to long words. A repeated measures ANOVA was used with task familiarity (2) and stimulus length (2) as within-subject factors. The last two separate RT analyses were performed on the task familiarity conditions because these could be separated in two groups of short and long words so individual key presses could be analyzed. Both groups of short and long words were subjected to a repeated-measures ANOVA with task familiarity (2) and key (5 for short, 7 for long words) as within-subject factors.

2.7 EEG parameters

The CNV was calculated by averaging EEGs for all trials without artifacts from all electrodes. Statistical analyses were performed on the values of the Cz and Pz electrodes as De Kleine and Van der Lubbe (2011) found relevant differences on these sites. Averaged activity was determined in 200ms intervals from -1000 to the go/nogo signal as these were the intervals where most differences in CNV might be expected (e.g. Jankelowitz & Colebatch, 2002). A repeated-measures ANOVA was used with task familiarity (2), stimulus length (2), electrode (2) and interval (5) as within-subject factors. After this analysis, it was decided that an additional analysis on the last interval and the Pz electrode was useful. Therefore, a repeated-measures ANOVA was used with task familiarity (2) and stimulus length (2) as within-subject factors.

3. Results

3.1 Behavioral measures

Before the behavioral data was analyzed, the incorrect and nogo trials were removed. The PC was 89% in total. The distribution of the PC over the dimensions Familiarity and Length were not unexpected and showed only small differences (PC 89.7 for familiar, 88.3 for unfamiliar, 91.8 for small and 86.2 for long words). Furthermore, a graphic representation of the mean RT's by both dimensions is presented in Fig. 2.

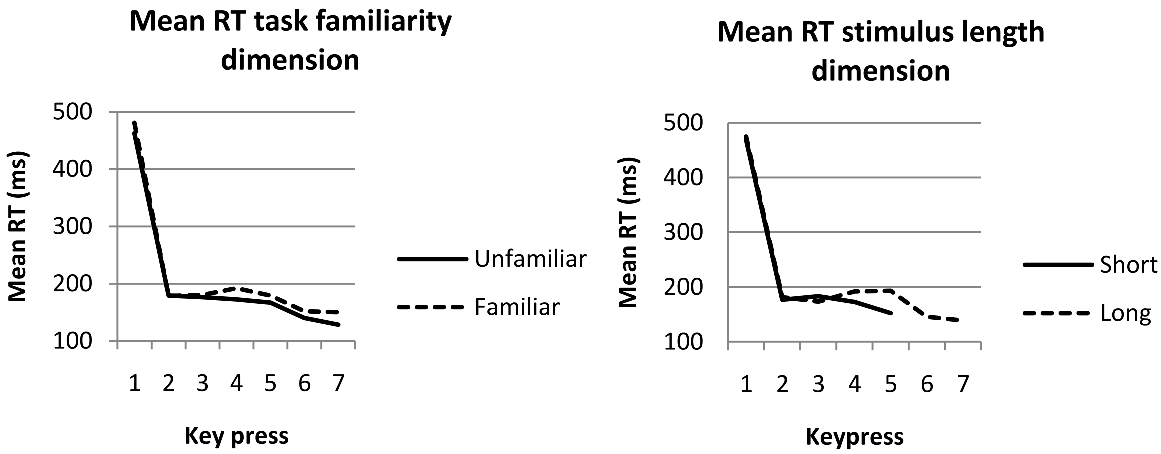


Fig. 2 Left: Mean RT for every key press by task familiarity dimension. Right: Mean RT for every key press by stimulus length dimension.

Response times for the first key press were shorter for the familiar words compared to the unfamiliar words (462,412 vs. 480,979 ms), *F*(1,14) = 7,030, *p* = 0.019. No significant difference was found between the response times for the first key press in the Length conditions *F*(1,14) = 0.885, *p* = 0.363. Also, no interaction effect was found for the response times of the first key press between the Familiarity and Length conditions F(1,14) = 0.559, *p* = 0.467.

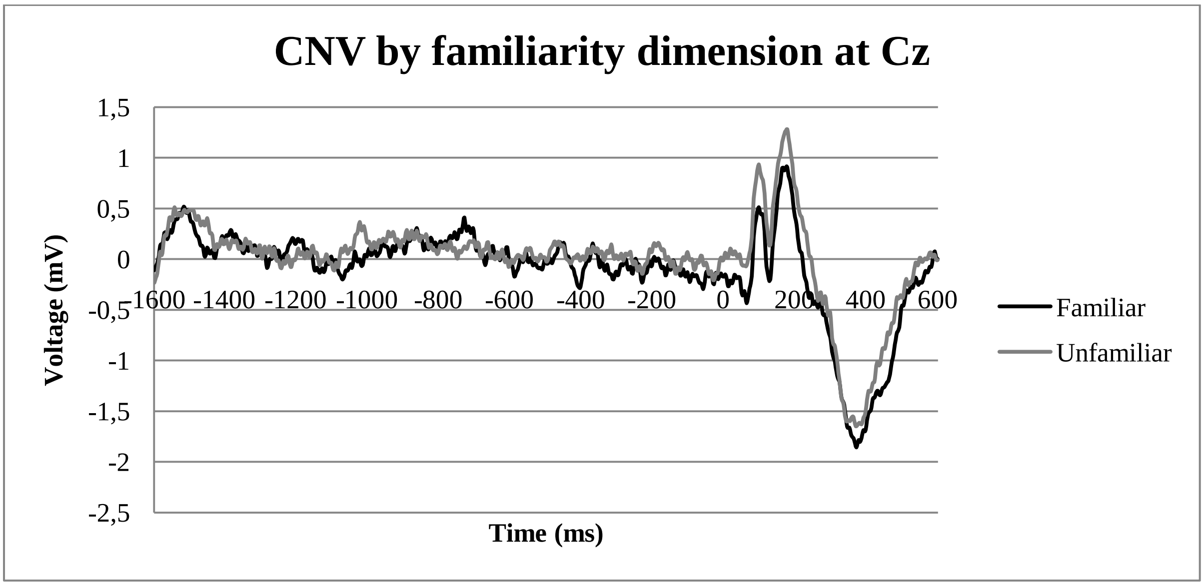
In order to compare the effects of the different dimensions on the overall RTs, average inter-key intervals (IKI; e.g.(Liang et al., 2008) were calculated. Analysis on the average IKIs revealed a main effect on task familiarity dimension $F(1,14) = 20.826$, $p < 0.001$. Familiar words were executed faster (165,806 ms) compared to unfamiliar words (176.132 ms). However, no effect on the stimulus length dimension was found $F(1,14) = 0.39$, $p = 0.846$. Also, no interaction effect was found ($F(1,14) = 0.82$, $p = 0.779$.

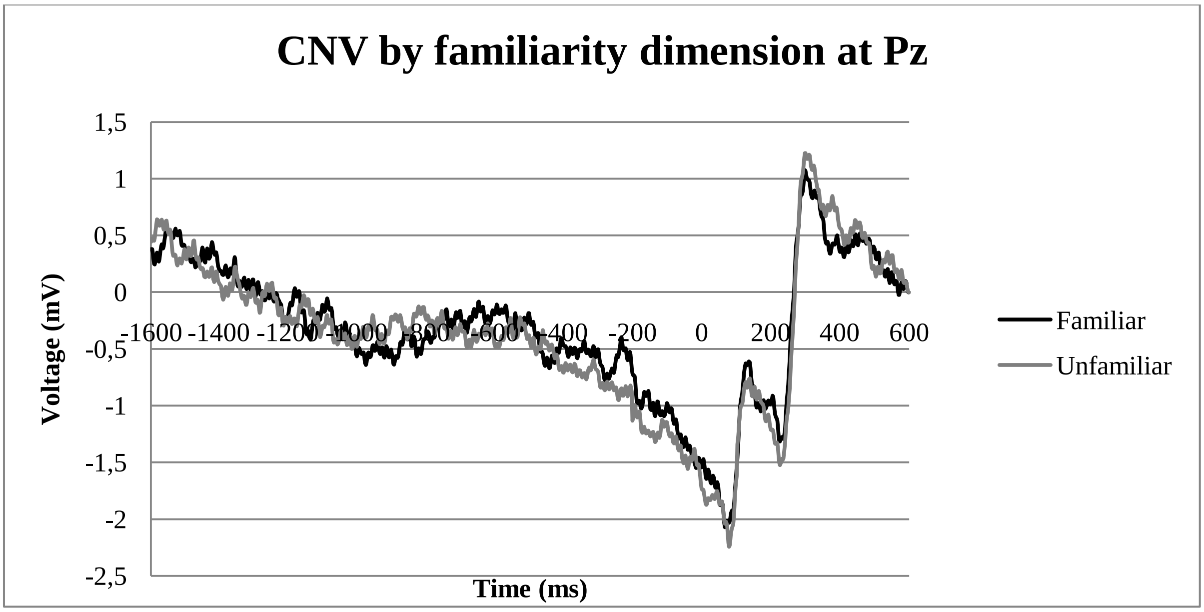
Two separate RT analyses were performed on the Familiarity condition for every separate key press, the first by comparing only short words, the second by comparing only long words. The analysis on short words showed a significant effect on Familiarity $F(1,14) = 13.354$, $p = 0.003$, and a significant effect on Key $F(4,56) = 274.531$, $p < 0.001$. However, no interaction was found between Familiarity and Key $F(4,56) = 1{,}789$, $p = 0.160$. The analysis on long words lead to similar effects on Familiarity $F(1,14) = 14.748$, $p = 0.002$ and Key $F(6,84) = 287.254$, $p < 0.001$, but also found a significant interaction effect between Familiarity and Key $F(6,84) = 3{,}374$, $p = 0.020$, showing an increased RT for the fourth and seventh key press for familiar words.

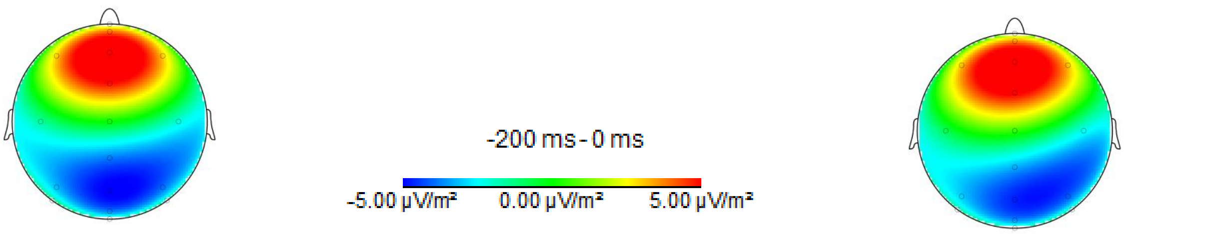
3.2 EEG analyses

The CNV topography maps of the four conditions as seen in Fig.3 and 4 were based on the averaged activity during the interval of 200 ms before the go/nogo signal. It particularly shows negativity at parietal and temporal sites. This can also be seen in the ERP plots of Cz and Pz shown in Fig. 3 and 4. The CNV is maximal in negativity at Pz while Cz reveals a hardly any negative tendency. Also, there is no overall distinct divergence between the dimensions Familiarity and Length for both Cz ad Pz. Further statistical analyses on the 1000-0 ms interval relative to the go/nogo signal confirm this. No significant differences were found for Familiarity $F(1,14)=1.183$, $p = 0.295$ and for Length $F(1,14)=0.463$, $p=0.507$, also no interaction effect was found $F(1,14)=0.238$, $p = 0.633$. However, a significant effect was found on Interval $F(4,56) = 35.297$, $p < 0.001$ and a marginal significant effect on Electrode $F(1,14) = 3.455$, $p = 0.084$, indicating a stronger negativity at Pz compared to Cz. Furthermore, an interaction effect was found on Electrode and Interval $F(4,56) = 5.863$, $p = 0.012$ which can be seen in Fig. 5.

Because an interaction effect between Electrode and Interval was found, additional analysis was performed on the -200-0 interval relative to the go/nogo signal for Pz because effects were expected to be maximal at this interval and electrode. An effect was found on Familiarity $F(1,14) = 5.009$, $p = 0.042$. On average, activity for the unfamiliar words showed more negativity. No effect of Length $F(1,14) = 1.944$, $p = 0.185$, or interaction $F(1,14) = 2.263$, $p = 0.155$ was found.



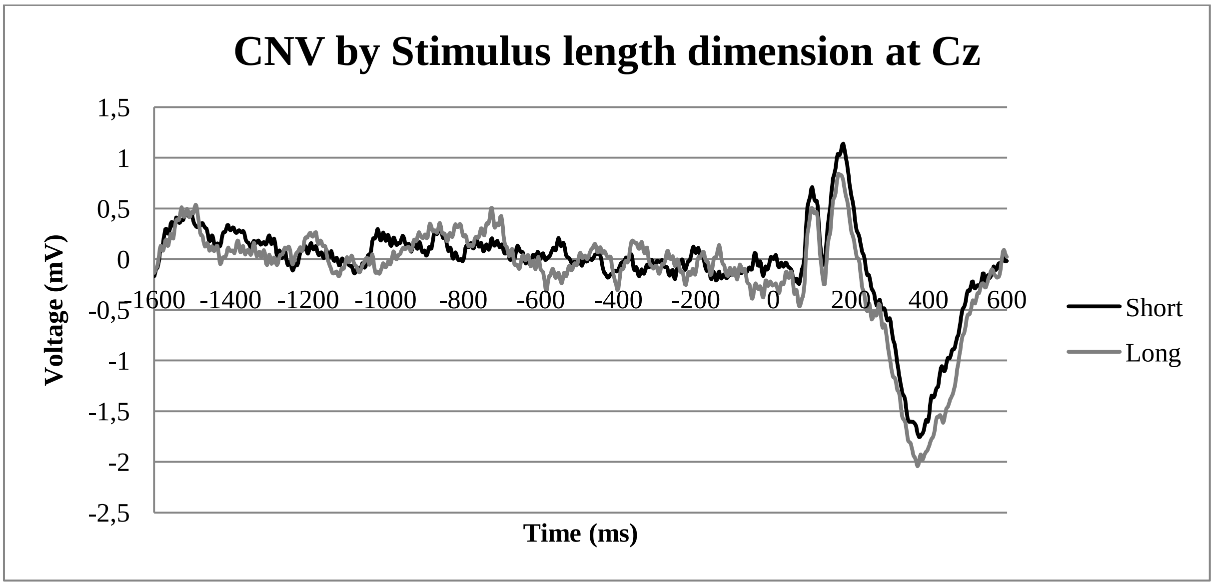


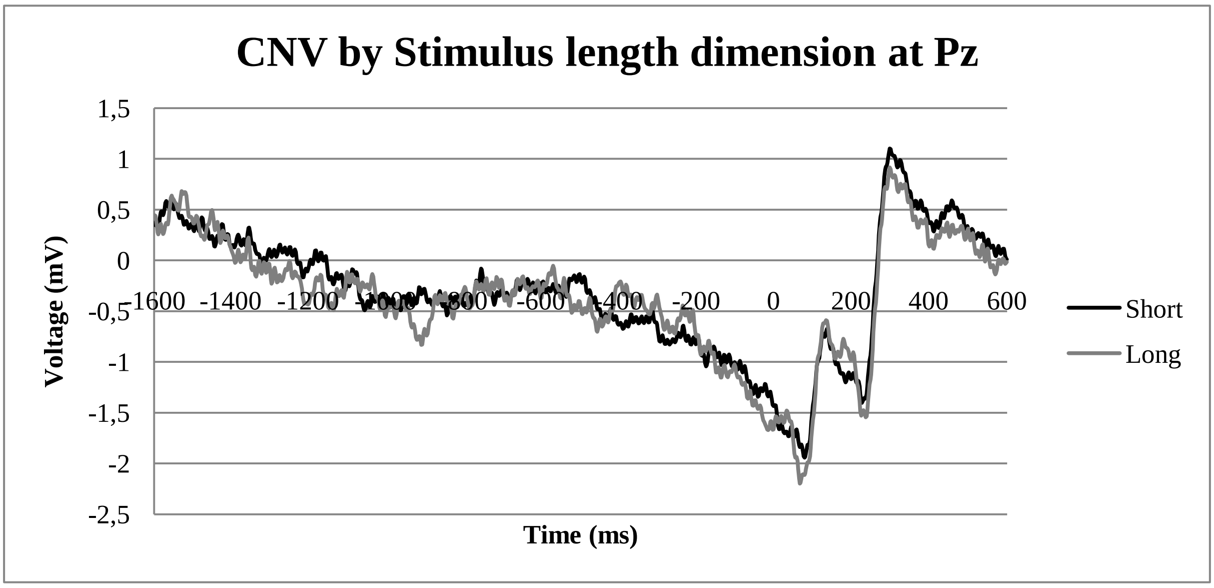


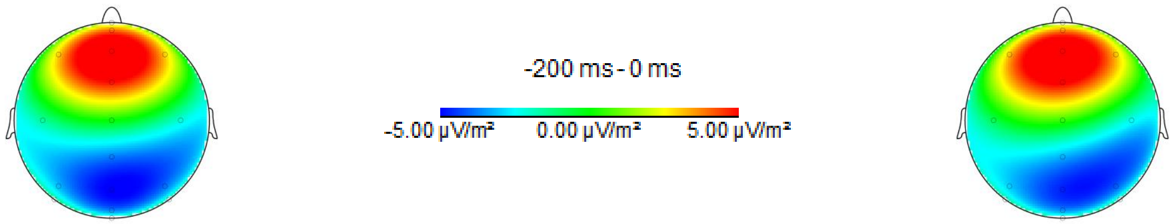
Familiar words topography.

Unfamiliar words topography.

Fig. 3 Top: Two ERP plots of the CNV by task familiarity dimension for the Cz and Pz electrode. Bottom: Topography maps of the familiar words (left) and unfamiliar words (right), based on averaged values of the last 200 ms interval before the go/nogo signal.







Short words topography.

Long words topography.

Fig. 4 Top: Two ERP plots of the CNV by the stimulus length dimension for the Cz and Pz electrode. Bottom: Topography maps of the short words (left) and long words (right), based on averaged values of the last 200 ms interval before the go/nogo signal.

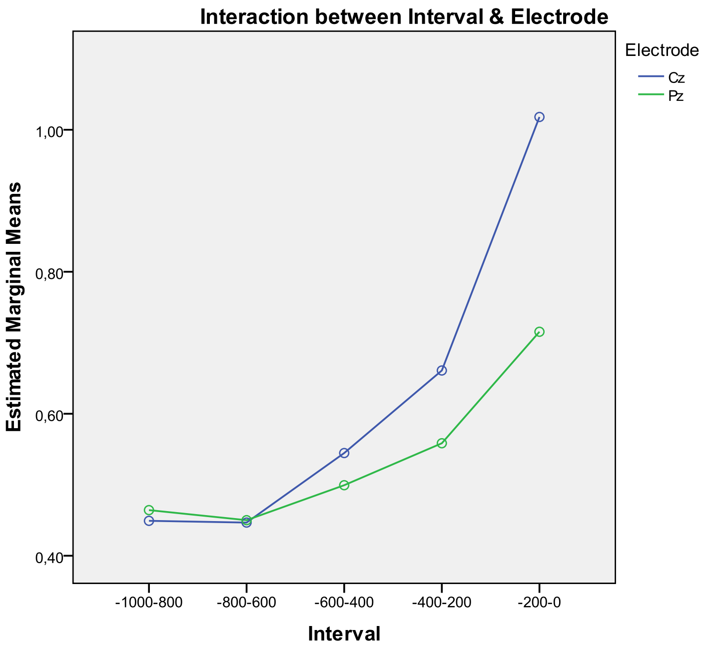


Fig. 5 Interaction effect between interval and electrode.

Discussion

The goal of the present study was to investigate how task complexity influences the cognitive processes of motor preparation. More specifically, two types of task complexity were looked into, namely task familiarity and stimulus length. Additionally, the experiment was designed to reflect a natural, everyday life typewriting task to maximize generalisability of the measured effects. Participants were asked to perform a variant on a go/nogo DSP task, in which they had to copy type words displayed on the screen if the go-signal was given. Words varied from short-Dutch words to long-Dutch words, short-nonsense words and long-nonsense words. EEGs were recorded in order to derive the CNV, which was used as a measure for cognitive processes of motor preparation. In the task familiarity dimension, it was predicted that the familiar words (represented by the Dutch words), would be executed faster and compared to the unfamiliar words (represented by the nonsense words). Also, in the stimulus length dimension, it was predicted that short words would be executed faster compared to the unfamiliar words. Furthermore, an interaction effect between the dimensions of task familiarity and stimulus length was predicted. The effect of task familiarity on execution speed and accuracy was expected to be enhanced for long words compared to short words. Regarding the cognitive processes of motor preparation, comparable hypotheses were made. For the task familiarity conditions it was predicted that the amplitude of the CNV would show increased negative activity for unfamiliar words compared to familiar words. In the stimulus length condition, the amplitude of the CNV for long words was expected to show increased negative activity compared to the short words.

As expected, it was found that familiar words were typed faster compared to the unfamiliar words. This indicates that there was indeed a certain difference in either the cognitive motor preparation or execution. However, no such effect was found for the words in the stimulus length dimension and also no difference in CNV amplitude was found in the stimulus length dimension. This is not in line with the findings in previous studies (Schröter & Leuthold, 2009; Verwey, 2001). This unexpected find may be explained because this study relies heavily on typewriting, a skill which the participants had highly developed. The before mentioned studies did not. A study with skilled typists (Salthouse, 1986) has shown that IKI's for skilled typist are shorter, it may therefore be more difficult to discern the averages from the short and long word conditions. Moreover, the difference of two letters between the small and long word conditions may simply be too small to reveal clear effects. The hypothesis on an interaction effect between the task familiarity and stimulus length dimensions was not confirmed in the RT results, as well as in the EEG data. Though no interaction was found, we cannot fully abandon this hypothesis. It may be that such an effect is present, but was not uncovered in our results. Because no clear effect on the stimulus length dimension was found, it could be that the interaction effect was also obscured.

The main effect on the task familiarity dimension in the behavioral response data may be further explained by the EEG data. Indeed, a significant difference in CNV amplitude was found at the Pz electrode during the 200 ms interval before the go/nogo signal, showing a stronger negativity for unfamiliar words compared to familiar words. This may indicate that some form of chunking occurs at the parietal sites. However, no such difference was found at Cz. In fact, the ERP plots for Cz reveal no outspoken tendency towards the negative at all. The maximal amplitude does not exceed the -0.5μV mark. These are not the characteristics of a typical CNV as found in previous studies (van Boxtel & Brunia, 1994; Caldara et al., 2004; Wild-Wall, Sangals, Sommer, & Leuthold, 2003). It can therefore be argued that no central CNV was present in this study. This may explain why no difference in amplitude was found in the task familiarity dimension at Cz.

The fact that a difference in the task familiarity dimension was found at parietal sites, but no CNV was recorded at central sites, may not be compatible with the initial hypothesis on the task familiarity dimension. The initial hypothesis was based on the idea that participants would be able to use motor chunks (Verwey, 2001) for familiar words and thus decrease the cognitive load and the CNV amplitude (De Kleine & Van der Lubbe, 2011). This explanation has pitted motor chunking as a key component in the reduction of cognitive load and thus a CNV effect was predicted over central motor areas (Jankelowitz & Colebatch, 2002; Leynes et al., 1998). Because this is not confirmed in the present results and the effect was only found at parietal sites, the effect may not be solely attributed to motor chunking. The parietal CNV has been known to reflect more than motor preparation alone (Leuthold & Jentzsch, 2002; Verleger, Wauschkuhn, R. van der Lubbe, Jaśkowski, & Trillenberg, 2000). Alternative explanations may therefore be necessary to explain the present findings. In order to shed light on this question, three possible approaches are given. It should be noted that these explanations do not necessarily oppose one another, but can be seen as different points of view.

One possible explanation (1) for the parietal CNV is suggested by Verleger et al. (2000). The authors propose that the parietal negativity may reflect the binding of stimulus and response as described by Milner and Goodale (1998). Milner and Goodale elaborated on the concept of two visual pathways, first introduced by Ungerleider, Mishkin and Macko (1983) and describes a dorsal and ventral visual pathway. The dorsal pathway is said to be connected with the question of “where” an object is located in space, or spatial characteristics of the world around us. The ventral pathway is believed to be associated with the question of “what” an object is, identifying and assigning semantic significances to the objects in view. So, in line with this theory, the parietal and temporal negativity found in the present study may be related to the activities of the ventral pathway and therefore the identification of the stimulus and not motor preparation. The lower CNV amplitude for familiar words may be evidence for a word chunking effect (Mewhort, 1972; Sakai, Hikosaka, & Nakamura, 2004) or a visual chunking effect, thus decreasing the load on the working memory (Leuthold, Sommer, & Ulrich, 2004; McCollough, Machizawa, & Vogel, 2007).

Another explanation (2) may be given by the concept of parieto-frontal connections (Rizzolatti, Luppino, & Matelli, 1998). The authors suggest that the motor system consists mainly of a network of connection between parietal cortical structures (superior parietal lobule, inferior parietal lobule) and frontal areas (motor areas, supplementary motor areas). Although connections exist between all parietal and frontal areas, some connections are more predominant compared to other, additional connections. These predominant reciprocal connections indicate that the involved areas work closely together and can be seen as a single motor unit. This may explain the parietal distribution of the CNV found in the present study. If the observed parietal negativity is indeed associated with this parieto-frontal connection, then this activity may be closely related to motor activity. The main effect on the task familiarity dimension found in the parietal area may then be interpreted as an early, more abstract form of motor chunking. It could be interpreted as a precursor of the motor chunking effect as described by De Kleine & Van der Lubbe (2011).

However, the two before mentioned explanations should be interpreted with caution. Although both the approach of the two visual pathways (Milner & Goodale, 1998) and the idea of the parieto-frontal connections (Rizzolatti et al., 1998) explain to some degree the parietal findings, both approaches still rely on central motor cortex activation to execute the movement. The absence of the central CNV found in this study is therefore not explained by either of them.

A third approach may be given to tackle this problem. The distribution of the CNV may change if the type of the task is altered (Leynes et al., 1998). Because the task in this experiment consisted of typewriting, a different CNV topography may be expected compared to classical DSP studies using meaningless sequences. A previous typewriting study also found a parietal effect and have suggested that parietal areas may also be involved in the production of movement sequences (Gordon et al., 1998). Furthermore, a functional magnetic resonance imaging study on skilled piano players also found parietal activation in regions such as the posterior parietal cortex (Itoh, Fujii, Suzuki, & Nakada, 2001). The results from the before mentioned studies seem to indicate that the parietal areas are of particular importance when a task involves highly developed finger motor tasks. It could be that the parietal areas relieve the central areas by taking over some of the highly trained and developed motor skills. Although further research on this statement is still necessary, there is some evidence that the parietal regions are capable of taking over the production of sequential movement (Pineiro, Pendlebury, Johansen-Berg, & Matthews, 2001). This may explain why no distinct CNV was found over central sites, but more clearly over parietal sites. The difference in CNV amplitude that was found in the task familiarity condition can in that case be attributed to a form of motor chunking because participants would be able to use motor chunks for familiar words, thus reducing the cognitive load.

The most likely interpretation of the three before mentioned approaches seems to be the third, which has suggested that the parietal areas may take over some of the more highly developed finger movements. This explains both the parietal difference in the task familiarity dimension and the absence of a central CNV.

One of the more exploratory goals was to investigate whether a more natural task comparable to an everyday life task influences the characteristics of the CNV. It can be concluded that the CNV characteristics are quite different compared to previous studies who used more stripped down tasks. These differences can be due to the fact that the typewriting task used in this study uses higher cognitive functions compared to the classical DSP task. It is likely that other meaningful everyday life tasks also use more higher cognitive functions. The present results are encouraging to further investigate the effects of natural tasks on the CNV as it may jeopardize the generalizability of studies who use controlled, stripped down tasks.

While interpreting the results of this study, it should be noted that the study was subjected to one important limitation. Although all participants had a certain degree in typewriting skill, there were still differences in typing speed. If cortical activity is indeed altered by the degree of skill (Pulvermüller et al., 2005) as suggested earlier in this discussion, then the difference in typewriting skill may have contaminated the averaged EEG values . A suggestion for further research would be that it is desirable to make a more precise distinction in the degree of skill of the participants. Also, it should be noted that the stimuli in the typewriting task were words and thus relied on linguistic cognitive processes. Little is known about the effects of linguistic components on the CNV, as most recent research on motor tasks employ visual-spatial stimuli for their experiments. It may therefore be problematic to compare results from these studies with the results from the present study.

In conclusion can be said that the most interesting findings in this study have been the absence of a central CNV, but a more pronounced CNV at parietal sites which contained a main effect on the task familiarity dimension. Although further research is necessary before a definite explanation can be given for the absence of the central CNV, the parietal effect on the task familiarity dimension may indicate that the parietal cortex plays an important part in the production of sequential movement. This means that the concept of motor chunking as described by De Kleine and Van der Lubbe (2011) may occur even earlier in the cognitive and on a higher cognitive level in highly developed motor skills.

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