EVENT-RELATED POTENTIAL CORRELATES OF FEEDBACK ANTICIPATION DURING MOTOR LEARNING

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OF FEEDBACK ANTICIPATION DURING MOTOR LEARNING

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and hereby certify that, in their opinion, it is worthy of acceptance.

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Abstract

Stimulus-preceding negativity (SPN), an ERP component that reflects the anticipation of feedback and other motivationally salient stimuli, has been proposed to play an important role in reinforcement learning. However, the relationship between the amplitude of SPN and learning is unclear. The current study aims to address the two competing theories in this topic. Mattox et al. (2006, Clinical Neurophysiology, 117, 2144-2153.) found that the amplitude of SPN gets larger with learning, which is congruent with the theory raised by Brunia et al. (2011, Clinical Neurophysiology, 122, 858-868.) that the SPN is a pure reflection of expectancy. By contrast, Moris et al. (2013, Psychophysiology, 50, 931-939.) found the opposite pattern of SPN, that is to say, that the SPN gets smaller with learning. They theorized that SPN reflects the amount of information the participant anticipates extracting from the feedback. The current study attempted to address this controversy.

On each trial of the present study, 60 young adult subjects were required to make four precisely timed key-press responses with a designated hand. Instructions for this timing were indicated by a pattern composed of four dots and line segments shown on the computer screen. After a brief (2.5 s) or long (8 s) delay, feedback was given. The instructed temporal pattern and delay were constant within blocks of 30 trials. The key point concerns the timing of the feedback. When feedback was provided after a short delay, SPN conformed to predictions of the feedback informativeness account and declined across trials. While in the long delay condition, SPN increased across trials consistent with the expectancy theory. This dramatic difference provides supportive evidence for the conclusion of Forde and Shohamy (2011, The Journal of Neuroscience,
that a change from short to long feedback delay causes a shift from procedural to declarative memory system.
Introduction

For over a century, reinforcement learning has been a captivating topic in cognitive and neurophysiological science. Psychophysiologists have made a great amount of effort to understand the neural basis of this process. An event-related potential (ERP) component, stimulus-preceding negativity (SPN), has been proposed to play an important role as an index of the expectation of response outcomes such as rewards or feedback.

The SPN, a slow brain wave, occurs when subjects are expecting a stimulus with motivationally relevant information that will appear in a few seconds (Brunia et al., 2011; Van Boxtel & Böcker, 2004; Chwilla & Brunia, 1991). It is generally larger at sites overlying the right hemisphere (Böcker, Baas, Kenemans, & Verbaten, 2001; Kotani et al., 2001; Brown et al., 2008; Ohgami et al., 2004). Some of the specific areas presumed to be involved are determined by the modality of the anticipated stimulus (Brunia & Van Boxtel, 2004; Kotani et al., 1999).

Parkinson's disease (PD) patients are reported to have a severe impairment of this ERP component as they learn to perform a perceptual categorization task (Hackley, Valle-Inclan, Masaki & Hebert, 2013; Mattox, Valle-Inclan, & Hackley, 2006). This may be due to the fact that feedback-based learning involves mesencephalic dopamine (DA) cells, which mediate reward anticipation processes. PD patients are known to have severe deterioration of midbrain DA pathways (Agid et al., 1987).

Changes During Learning

SPN indicates the anticipation of an upcoming feedback regarding task performance, and the amplitude of SPN increases steadily prior to the onset of that feedback (Brunia, van
Boxtel, & Bocker, 2011; Damen & Brunia, 1987; Kotani et al., 2001; Kotani et al., 2003; Masaki et al., 2006; Masaki et al., 2010). According to previous studies, the larger the amount of information that the feedback provides, the higher the amplitude the SPN is (Kotani et al., 2003; Fuentemilla et al., 2013).

However, the relationship between the amplitude of SPN and the progression of learning from feedback is a controversial topic. Mattox et al. (2006) found that the amplitude of SPN gets larger as learning progressed, which is consistent with the theory proposed by Brunia (Brunia, 1988; Brunia, Hackley, van Boxtel, Kotani & Ohgami, 2011). That theory implies that the SPN is purely a reflection of expectancy, and expectancies should improve over the course of learning. This is because increased learning should lead to better understanding of the task and improved prediction about outcomes. The SPN amplitude should increase as a result. On the other hand, the results of Moris et al. (2013) portrayed the opposite scenario. They found that the amplitude of SPN shrinks as learning progresses. Under their interpretation, this is due to the feedback becoming less needed and less informative as the experiment continues. The amount of information provided by the feedback decreases as learning increases. In addition, by comparing correct and incorrect trials, Moris and colleagues also found that SPN amplitude on incorrect trials tended to be larger than on correct trials especially on later trials. After emitting a response that is poorly considered, participants would be keenly interested in feedback. The authors suggested that the role of SPN in the learning process is preparation to extract information. The main purpose of the present experiment is to address this apparent contradiction concerning the role of SPN in feedback anticipation.
Two Memory Systems

In addition to understanding the function of SPN in feedback anticipation, the current study is also intended to test the roles of two neural systems in reinforcement learning: the striatal system and hippocampal system. Researchers used to assume that the gradual acquisition of motor skills during reinforcement learning depended solely upon the procedural memory system, mediated in the striatum (Knowlton, Mangels & Squire, 1996). However, more recent evidence suggests that the procedural and declarative (hippocampal) systems interact competitively during reinforcement learning (Foerde, Braun & Shohamy, 2012; Poldrack & Packard, 2003; Weinberg, Luhmann, Bress & Hajcak, 2012).

According to research of Foerde and Shohamy (2011), the roles of these two memory systems are influenced by feedback timing. In a probabilistic learning task
(Figure 2), subjects needed to guess which of two flowers would be preferred by a particular butterfly. Those two options have unequal probability to be correct, one was 83% and the other 17%. In addition the feedbacks were given at one of two possible delays, 1s vs. 7s. Researchers found that in the immediate feedback condition (1s), PD patients had learning deficits in comparison with normal people. While in the delay feedback condition (7s), PD patients performed no different from healthy adults. The explanation offered by the authors was that, in immediate feedback situations, the procedural memory system dominates, while in delayed feedback, it is mainly the declarative memory system that functions. We know that PD patients have impaired basal ganglia (including the striatum), which leads to malfunction of procedural memory (Knowlton, Mangels & Squire, 1996). However, when only hippocampus-based memory was needed, the PD patients had no trouble to function, so they did as well as the control subjects.

Figure 2. Forde & Shohamy (2011) task illustration. The subject needs to pick between two flowers to guess which is preferred by the butterfly. The two flowers have unequal probability of being chosen by the butterfly (83% vs 17%).
Their second experiment used fMRI (functional magnetic resonance imaging) to assess brain activity in healthy young adults performing a similar task. It provided converging evidence. The striatum was relatively more active during immediate feedback trials, whereas the hippocampal system was more involved in delayed feedback trials (see Figure 3). Using a very different paradigm, Maddox, Ashby and Bohil (2003) showed that learning on a feedback-dependent perceptual categorization task ("information integration" using procedural memory) was impaired when feedback was delayed, but learning on a rule-based categorization task using declarative memory was not affected. An ERP study also supports the conclusions of Foerde and Shohamy, Weinberg and colleagues (2012) varied feedback delay between 6 and 1 seconds in 2-choice gambling task. The Feedback Negativity component (an index of reward-related activity in the anterior cingulate cortex) was absent in the 6s condition but clearly present in the 1s condition.
Eligibility Traces

In order to help understand the consequences of feedback anticipation at short and long delays, the current study also utilizes another ERP measure, the lateralized readiness potential (LRP). This component was used to monitor motor cortex activity during task performance. LRP is a slow negativity that occurs preceding a hand or foot response (Kutas & Donchin, 1980). It is solely movement-related and reflects brain preparation for a specific motor response (Hackley & Miller, 1995). The starting point of the negative potential indicates the beginning of the brain preparation that is specific for a left versus right motor act. Size of LRP depends on the characteristics of the upcoming response (e.g. limb, movement direction, speed, etc.).

Figure 3. Experiment 2 of Forde & Shohamy (2011). It shows that with a change from immediate to delayed feedback, the usage of brain areas shifts from striatum to hippocampus.
extent and force; Smulders & Miller, 2012), and the complexity of response (Hackley & Miller, 1995). In addition, LRP can be detected even when the response is planned but not completed (DeJong et al., 1990; Miller & Hackley, 1992). For example, in a stop-signal paradigm (Logan, 1994), the LRP can still be observed even when subjects are signaled to halt a response that they have already begun to initiate (DeJong et al., 1990).

The LRP in the current experiment is recorded in order to test whether participants hold their response in working memory as they await feedback. If they do rehearse their just-emitted response during the pre-feedback period, it might be possible to record an LRP during this interval. This would constitute evidence for the existence of “eligibility traces”. Eligibility traces are hypothetical representations in memory of recent actions that could have yielded the delayed outcome (Sutton & Barto, 1998). This is an important, but unconfirmed, construct in reinforcement learning theory.

**Rationale**

A sequential motor learning task was utilized in current study. On each trial, subjects were required to make four precisely timed key-press responses with a designated hand. Instructions for this timing were indicated by a pattern composed of four dots and line segments shown on the computer screen (Figure 4). After a short (2.5 s) or long (8 s) delay, feedback was given.
In summary, current study aims to test a number of questions concerning feedback anticipation. The first one is to understand the functional correlates of SPN in feedback anticipation and address the controversy raised by previous studies. Does the SPN get smaller or larger as a task is learned? The second is to examine the roles of two distinctive memory systems in reinforcement learning. Does manipulation of the length of feedback delay period differentially affect the SPN? The third question is, as people wait for feedback, do they hold a motor representation in working memory so that they can compare this representation with the feedback in order to learn and thereby improve their response for the next trial? (Further background information about these topics, especially the specific electrophysiological measures, is provided in Appendix A.)
Method

Participants

In total, 48 University of Missouri undergraduate students (22 males and 26 females, average age = 21 years) from an Introductory Psychology course and 12 young adult volunteers from the community (8 male and 4 female, average age = 22 years) comprised the sample. Individuals with self-reported major visual impairments were excluded from the study, as were those with psychiatric disorders. All participants gave their informed consent according to procedures approved by the IRB. Subjects received course credits (1 credit per half an hour) or money (7 dollars per hour) in compensation for their participation. Four subjects were rejected from further data analysis due to poor task performance and two subjects were eliminated due to problematic recordings. In addition, 9 subjects were rejected by later data analysis criteria (describe below).

Experimental Stimuli and Procedures

As shown in Figure 4, each trial began with the instructional template to indicate the task. The task in current study was to make four quick key-presses based on the template shown on the computer screen. The instructional template consisted of four thick, white, straight lines of varying length that began with big dots. Each white dot indicated a key press. The length of the straight line after each dot indicated the length of time that the subject would need to hold the key down. The four key-press lengths in total were to add up to 1 second. Two fingers of the same hand were used for each response, to generate a larger LRP.
Subsequently, a fixation mark occurred at the center of the screen as a warning signal. Then an imperative stimulus (arrow) was displayed to indicate which hand the subject should use to make the response. Its offset served as the ‘go’ signal. Once the subject saw the arrow disappears from the screen, he could start to produce the movement corresponding to the template. Accuracy was emphasized over speed.

Each block involved only one template. There were 9 blocks in total, but the first was practice to let subjects become familiar with the task. Subjects were not told that the first block was practice. Each block contained 30 trials, 15 trials using the left hand and the other 15 using the right hand, randomly determined. Upon completion, the subject was asked to rate how hard the previous block was on a scale from 1 to 9, (1 indicated very easy and 9 indicated very hard). They were then informed of how many points they had earned in that block and how many they had earned in total so far. The blocks were counterbalanced in an A- ABABABAB and A – BABABABA format (A indicates short delay condition, and B indicates long delay condition, the practice block was always a short delay condition).

After the volunteer arrived the lab, the session began with a short verbal introduction to the experimental procedures and apparatus. If the volunteer was willing to participate, a written consent form was provided for him/her to sign. After written consent had been acquired, subject was provided inventories showed in Appendix C to fill out while the experimenters applied electrodes. After electrodes applied completely, the subject was seated in the recording booth. The participant was instructed to keep their head still and look straight to the computer screen as a period of resting EEG is recorded.
for later spectral analysis and correlation with questionnaire data, by Dr. Sergii Tukaiev (not part of my thesis).

Figure 4. An example of trial structure for the keypress-timing task. The general structure is the same except the feedback delay varied in length across two conditions.

After making sure that the task described above was understood, the experimenter told the participant that he could start the experimental program any time by pressing any key on the keyboard. It is worth to mentioning that, to discourage subjects from memorizing the movements according to the key-press sound from the keyboard, a white noise (70 dB) was played during the entire experimental session to mask the key-press sound.

In the 8-second condition, the computer screen went blank when the movement sequence was finished. This is analogous to the conditioned stimulus (CS) –
unconditioned stimulus (US) delay in trace conditioning. In trace conditioning, there is an empty delay between the CS and US and the hippocampus is required here to bridge the gap between the two stimuli (Rawlins, 1985). In the 2.5 sec condition, the template remained on the screen, analogous to a sustained CS in delay conditioning. This sort of Pavlovian conditioning can occur even in animals whose hippocampi have been destroyed. Then, at the conclusion of the delay interval, a feedback display in the same format as the template was shown on the screen portraying subject's responses.

Based on the match between the template and subject's response, the screen informed the subject whether his response was correct or incorrect and how many points he had earned or lost in that trial (e.g., "+7 points"). The correctness and points in each trial were calculated according to the correlation between the instructional template and subject’s response. The correct threshold was set at $r = 0.8$. The points awarded equaled the correlation multiplied by 10. Each trial was worth a maximum of 10 points or a minimum of -10 points. The total points the subject earned based on his performance supposedly determined whether he could receive a chocolate bar as a reward at the end of the experiment. In fact, all participants were told that their performance had been good enough to qualify for the chocolate. The feedback stayed on the computer screen for 1 s. As the inter-trial interval began, a new screen appeared that instructed the subject to press both keys at the same time to move on to the next trial.

After the experiment, electrodes were removed and the participant was provided with an oral and written debriefing, thanked, and given their chocolate bar.

**Physiological Recordings**
The EEGs were recorded using Ag/AgCl electrodes embedded in an elastic cap (Easycap; Herrshing, Germany) and filled with Abralyte V19 electrode gel. Measurements were obtained from central, frontal, parietal, and temporal electrode sites (C3, C4, F3, F4, P3, P4, T5, T6, Fz and A1) with bandpass range 0.01-30 Hz, referenced on-line to the right ear lobe. Bipolar horizontal and vertical electro-oculograms (HEOG and VEOG), used for rejection of trials with artifacts, were also obtained with the same bandpass (0.01-30 Hz) as the EEGs. EMGs of m. flexor digitorum profundis, which controls finger movements, were recorded with bipolar pairs of electrodes positioned over the left and right ventral forearms, using a bandpass of 1-300 Hz. All electrode impedances were below 5 kΩ except that left and right arm electrodes were below 15 kΩ.

**Data Analysis**

The eye-movement channels (i.e. horizontal electro-oculograms, HEOG, and vertical electro-oculograms, VEOG) were used during artifact rejection. All subjects’ EEG data were run through the Gratton method program (Gratton, Coles & Donchin, 1983) for correcting blink and eye-movement artifacts. Trials with amplitude above 120 microvolts (µV) in either EOG or EEG channels were rejected by using an automatic artifact rejection program in the EEGlab. In addition, EMG (electromyograms) recorded from both left and right forearm were used to assess finger movements. Trials with finger movements during the delay period were rejected, so that any pre-feedback LRP observed could be inferred to reflect working memory, not an actual finger movement. Nine subjects were rejected due to not sufficient amount of trials.
The EEG, EOG, and rectified EMG were then signal-averaged separately for each participant, according to delay interval and first versus last 10 trials of each block of 30 trials. The amplitude of the SPN was quantified as the averaged amplitude 500 ms immediately before the feedback onset in the short delay condition and 6000 ms to 3000 ms before the feedback onset in the long delay condition. This window was chosen post hoc, based on the grand average waveforms. In addition, an a priori decision was made to conduct separate analyses on the F4 data, because that typically is where the SPN is largest and that is where Moris found the biggest learning effect. In some additional analyses, correct versus incorrect feedback on the preceding trial was also used as an analysis factor (see Appendix B).

To assess motor cortex activity, the LRP was calculated in a double subtraction technique between the left and right hemisphere potentials (details are described in Appendix A). Its amplitude was quantified as the average voltage 200ms immediately before the feedback onset in both conditions. LRPs are conventionally analyzed at sites overlying M1. However, in the present study, they are also analyzed at frontal (i.e. F3 and F4) and parietal sites (i.e., P3 and P4), to assess possible correlates of eligibility traces.

The behavioral response in each individual trial was calculated via within-trial correlation between the instructed keypress duration and the actual duration of the four keypresses. This was main measure of task performance. Note that this measure is not sensitive to overall duration. For example, if a subject were consistently slower than instructed by a fixed amount, there would be no effect on the correlation coefficient. The EMG bursts provided supplementary information about movement. They were analyzed in a manner similar to the SPN.
Per condition means were analyzed using repeated measures analysis of variance (ANOVA). The primary factorial structure was 2 x 2 x 8 (delay x trials x electrodes). ANOVAs with alternative structures are described in context below, along with t-tests. Amplitudes were quantified as mean voltage within a window. These windows and baseline intervals are specified below separately for the various measures. A rejection region of .05 was adopted throughout, but marginally significant effects are noted when they are judged to be of interest to the reader.
Results

Behavioral Data

There was a significant improvement in accuracy between the early and late portions of blocks, that is to say, between the first and last 10 trials within blocks of 30 trials. The averaged correct response rate (figure 5) increased from 81 to 87 percent in the short condition, and from 86 to 90 percent in the long condition, $F(1, 44) = 43.01, p < .05)$. This confirms that learning did take place.

Electromyography (EMG)
EMG bursts during early and late trials (1st and 3rd ten trials) within a block overlapped closely in both short and long delay conditions (Figure 6 & 7, bottom right). The average duration of both EMG bursts was about 2s despite instruction that the four responses be completed in one second. Notably, the large EMG peak reflecting the last key press is 10 \( \mu \text{V} \) and 9.5 \( \mu \text{V} \) in short and long condition respectively and dramatically different from the other bursts, which blurred together. Although they were not instructed to do so, nearly all subjects pressed harder on the last key response than on the first three responses. The close overlap of waveforms for the early and late trials within a block supports the assumption that learning effects on the SPN were not due to gross changes in the overall intensity or duration of the motor response.

**Stimulus-preceding Negativity (SPN)**

In contrast to the EMG data, divergent shapes of the SPN waveforms were clearly evident in the short and long delay condition (Figures 6 & 7). In the short delay condition, later trials produced lower amplitudes of the SPN. However, in the long delay condition, the pattern was reversed. A 2 x 2 x 8 ANOVA of delay duration, trial sub-block (1st vs. 3rd ten trials) and electrode position on SPN amplitude was conducted with SPN measured from 100 ms to 500 ms prior to feedback. An interaction was found between delay duration and trial sub-blocks was found (\( F (1, 44) = 4.20, p < .05 \)), confirming the reversal of learning effects between short and long delays. Two separated t-tests on F4 with different delay conditions were then conducted. In the short delay condition, a significant learning effect was found between 500 and 0 ms prior to feedback (\( t (1,44) = 2.15, p < .05 \)), while in the long condition, this effect was found between 6000 ms to 3000 ms before feedback (\( t (1, 44) = 2.25, p < .05 \)). It should be noted that these effects
were small and only significant with post hoc selection of measurement windows. In the short delay condition (Figure 6), the largest difference between early and late trial sub-block occurred at sites overlying the right frontal lobe (i.e., F4), as expected from Moris et al. (2013). While in the long delay condition (Figure 7), the numerically largest effect occurred at the right temporal lobe site (i.e., T6).
Figure 6. SPN, LRP and EMG results of short delay condition. Time 0 is the onset of feedback. The numerically maximal effect of SPN occurs on the F4 channel. Note that negativity is graphed downwards in this figure.
Figure 7. SPN, LRP and EMG results of long delay condition. Time 0 is the onset of feedback. The maximal effect of SPN occurs on the T6 channel.
**Lateralized Readiness Potential (LRP)**

LRPs were computed at frontal, central and parietal lobes and measured at a window extending from 500 to 0 ms. As shown in Figure 8, there no significant pre-feedback LRP found in either short or long condition. In addition, the differences between early and late trial sub-blocks were also tested in accordance to LRP, but there was no significant difference in either conditions, $F(1, 42) = .005, p = .94$; $F(1,42) = .82, p = .37$, for short and long delays, respectively. This shows that variations in the SPN across trials are not likely to be due to movement-related potentials such as postural adjustment of the hands after the response is completed. It also suggests that eligibility traces, should they exist, are not manifest at the level of sensori-motor cortex. Similar analyses were also conducted during the keypress response itself in time interval from 4500 to 2500ms and 10000 to 8000 ms prior to feedback in short and long delay, respectively. No significant learning effect was found in either conditions, $F(1, 42) = 1.5, p = .2$; and $F(1,42) = .13, p = .7$, for the short and long conditions, respectively.
Figure 8. LRP results of individual topographical area. Panels on the left are for the short delay condition and the ones on the right are for the long delay condition. No significant LRs were found during either delay period, as measured from 500 to 0 ms.
Discussion

In the current study, I recorded subjects’ electrophysiological activity during a motor task with two different feedback delay conditions. The findings help resolve a discrepancy with regard to the role of SPN in reinforcement learning, a discrepancy between the contention of Moris et al. (2013) that SPN reflects the informativeness of the feedback, and Brunia et al. (2011) that SPN reflects outcome expectancy. By comparing SPN in short and long feedback delay conditions, the current experiment provides evidence in favor of both theories. Brunia’s and Moris’s theories about the role of SPN in reinforcement learning applied under different conditions. Results in the short delay condition provide support for Moris’s theory that SPN reflects the process of preparing to extract information contained in the feedback. With progress across trials, useful information included in the feedback decreases. So, under this interpretation, the amplitude of SPN during the short feedback delay condition in my experiment became smaller. On the other hand, results for the long delay condition replicated Mattox’s (2006) results. The amplitude of SPN increased as the experiment progressed. This finding supports Brunia’s theory that SPN is a reflection of outcome expectancy. The more the subject practices the task, the better the expectancy that the subject can form about the upcoming feedback. The anticipation produces a larger amplitude SPN.

In addition, these divergent results in the short and long conditions provided converging evidence for the usage of different memory systems in reinforcement learning (Foerde & Shohamy, 2012). For the short delay condition, the largest SPN difference between early and late phase of learning tended to be in the location of F4 electrode area. This electrode site overlies the right inferior frontal gyrus and the right anterior insula.
area, which are involved in motivational salience (Brunia, et al., 2011). Therefore, in the short delay condition, the procedural memory system may have been used. However, in the long delay condition, the largest SPN difference between early and late phase of learning tended to occur in a different location, the T6 electrode area. Also, the shape and polarity of the difference between waveforms in the early and late trials of the two delay conditions were quite different. This could indicate that, in the long delay condition, subjects switched to the hippocampal memory system and used declarative memory while performing the task. As trials progressed, subjects may have been able to articulate hypotheses to themselves during the delay (e.g., “Maybe I pressed for too long on that third keystoke.”)

The individual electrode positions I found to have the largest learning effects in the short or long delay conditions, i.e. F4 and T6, are roughly congruent with the findings of Ohgami et al. (2014) on the origins of SPN. Their results showed that the right anterior insula and right occipital lobe scalp sites showed the strongest factor loadings in a principal components analysis for SPNs emitted while the subjects were waiting for visual feedback. It is worth to note that there were no electrodes in the occipital lobe area in the present study. The closest one is the T6 electrode. The locations of F4 and T6 lay with the two regions Ohgami and colleagues reported. In addition, in the current study, the waveforms of SPN of early trials and late trials in the long condition converge together right before the feedback. This indicates that some effects occurred here that are not affected by learning. To take both of these two studies into consideration, we might be able to say that SPN is produced by different sets of brain areas and that their involvement varies according to feedback timing.
In contrast with SPN data, the current results did not show any significant effects of learning on LRPs in either long or short delay conditions. This might for at least three reasons. Firstly, subjects might not be able to hold the previously executed motor movements in their memory in a concrete, hand-specific form even for the short delay condition. Eligibility traces might be very abstract representations of movements mediated by non-lateralized brain structures. Secondly, the task might be too easy for the subjects to hold and rehearse in the delay period, so they didn’t really to try to compare their movements with the pattern. They could have used a verbal or visual representation, for example, “Short - long - medium - short”. Finally, during the delay period subjects might not have been able to hold their hands and arms still and their muscles may have moved, perhaps involuntarily. Therefore, lateralized activity due to these movements might have obscured any LRPs associated with memory of the keypress sequence.

**Conclusions and Limitations**

Though the current study achieved its goals, there are still some limitations that need to be addressed. Both conditions in the current study contained feedback regarding the subjects’ response, so there was no control for non-feedback related processes. In other words, the SPN might actually have included a delayed response to the imperative stimulus or the keypress sequence, rather than purely reflecting feedback anticipation.

Based on limitations of the current study, the next step of confirming the current findings would be to conduct an experiment with a control condition for non-feedback processes during the delay interval, i.e., a no-feedback control condition. I am currently collaborating on such a new study. In addition, the present study was only performed in a
normal healthy population, but comparisons with a clinical population such as Parkinson’s disease patients who have deficits in dopamine might be able to distinguish striatal versus hippocampal mechanisms. A follow-up experiment with PD patients could be conducted to extend the current findings.

In conclusion, timing of feedback matters. The timing of feedback determines the different activation of brain areas, as shown in Forde and Shohamy (2011), and the functioning of varied memory systems. When the feedback to a motor task was given in a short time manner with sustained display of the response cue, the striatal system may have been activated and the procedural memory system engaged. The finding of larger SPNs on early trials is congruent with Moris’s (2013) theory that SPN reflects the amount of information provided by the feedback. However, if the feedback is delayed for a few seconds and the display of the response cue is interrupted, the system may have shifted to declarative memory and the hippocampal system. This effect supports Brunia’s (2011) theory that SPN is a purely a reflection of expectancy and should improve over the course of learning. Therefore, both Brunia’s and Moris’ theories are correct but they only partially depict this whole system. However, in the absence of behavioral or biological markers of the two memory systems, the present results can only be regarded as suggestive.
Reference


Appendix A

**ERPs Involved in Anticipation**

During the waiting interval, the subject prepares his response and anticipates the stimulus, three anticipatory slow waves are involved: the bereitschaftspotential (BP), the contingent negative variation (CNV), and the stimulus preceding negativity (SPN). The timing and occurrence condition of these three components are different.

The first negative potential is BP. It is also called readiness potential (RP) (Komhuber & Deecke, 1965), which is a negative slow brain wave that can be observed before a voluntary motor movement occurs. The reason why it called readiness potential is the occurrence of BP seems like the brain of the person who is about to produce the movement is preparing his body to execute such movements. In order to acquire BP in a typical experimental environment, subjects are required to make a series of voluntary self-paced button-press finger movements (Brunia, Van Boxtel, & Bocker, 2012). The amplitude of BP gradually increases as the movement execution nearby.

Usually, BP is composed by two components: a slow increasing early component, which starts between 2000 and 1500 ms prior to movement onset, and a steep increasing late component, which can be observed 400 to 500 ms prior to the movement (Brunia et al., 2012). In addition, there are two more subsequent components related to this process: premovement positivity (PMP) and motor potential (MP), which is a sharp increase in negative amplitude after PMP and occurs around 80 ms before movement onset.

Cortical origins of the two components of BP are found to be distinct. According to Deecke and colleagues (1976), due to the largest amplitude of early BP is observed in the midline, the origin of early BP might be in supplementary motor area (SMA). On the
other hand, due to contralateral predominance of the late BP and the MP, their origin might be from the primary motor cortex (MI). However, the origin of the PMP is still unknown.

Studies based on clinical subjects found that BP is affected by some disorders, such as Parkinson’s disease (PD) and schizophrenia. Colebatch (2007) found that the early stage of the BP is reduced in PD but the late stage is relatively the same in compare with healthy control subjects. In addition, the more complex and self-induced free movements, the greater reduction. For schizophrenia patients, the reduction effect is on both early and late phase of BP (Westphal, 2003).

Furthermore, early and late phase of BP are proposed to have different function. The latency of early phase is found to start later for high rate movements (Kornhuber & Deecke, 1965), simple movements (Lang et al., 1991) and hand movements (Brunia & Van den Bosch, 1984), in compare with low rate movements, complex movements and foot movements. Meanwhile, as mentioned before, subjects with PD have reduced amplitude of early BP. This may due to that PD patients have difficulty with response selection (Van den Wildenbergen et al., 2006). Therefore, the early phase of BP might be related with the selection of the appropriate motor strategy from memory. On the other hand, the late phase of BP can be influenced by extremity, force and external factors, such as feedback (Brunia et al., 2011), but not the early phase. Therefore, the late phase of BP is to prepare the specific motor parameters for the upcoming motor movement (Brunia et al., 2011).

**Contingent Negative Variation (SNV)**
The second important negative slow potential involved in anticipation is CNV. It can be recorded during the interval between a warning signal (S1) and an imperative stimulus (S2), but in order to get this potential, a task is necessary. Due to the process to trigger CNV component involves both memory, attention, emotional information and task movements, the topographical distribution of CNV depends on the motor movements and the type of information that stored in memory to carry on to activate the movements (Brunia et al., 2011).

The CNV component, as BP, is also found can be influenced by dopamine (DA) (Hansenne et al., 2000). The relationship between the dose of DA and the amplitude of CNV is an inverted U shape (Tecce, 1990). According to studies conducted by Verleger and his colleague (1999 & 2004), the amplitude of CNV reduced in Parkinson disease and schizophrenia patients, whose DA system is compromised.

The function of CNV, regardless of early or late components, is similar with the respective component of BP (Brunia et al., 2011). The early component of CNV is responsible for selecting a motor strategy from memory towards the task reflected by S1, while the late component of CNV reflects the specific motor and non-motor response to the S2, in other words, SPN.

**Stimulus-Preceding Negativity (SPN)**

The last important potential in the anticipation process is SPN. SPN is a right-hemisphere dominant slow brain wave (Brunia et al., 2011). The occurrence of SPN reflects brain’s preparation for the upcoming event or action. Therefore, its scalp distribution depends on the modality of the event and action.
SPN can be triggered by stimuli that providing knowledge of results (KR), but it only shows up when a true feedback occurs. Chiwilla and Brunia (1991) used a time estimation task to test this notion. They used three conditions in this study: real feedback, false feedback and no feedback. At last, they only observed SPN in real feedback condition, and no SPN in either no feedback condition or false feedback condition.

SPN can also be found prior to affective stimuli. Kotani and his colleagues (2001) compared the amplitude of pre-feedback SPN in both positive and negative feedback stimuli. They found that the amplitude of SPN under reward condition (i.e., received a monetary reward for accurate time estimations) was larger than under no-reward condition. They also found that the amplitude of pre-feedback SPN in noise condition (i.e., received a loud noise for inaccurate time estimation) is larger than pure tone condition. Other studies also support the effect of emotions on SPN. Takeuchi and his colleagues (2005) reported that frontal SPN was able to be elicited by negative emotional pictures. In addition, Bocker et al. (2001) also reported that SPN could be induced by fear in a threat-of-shock experiment.

The amplitude of SPN grows with feedback approaching. The absolute amplitude of SPN affects by the amount of information reflected in the feedback. Moris and his colleagues (2013) equally separated each block of trials into four parts according to their sequence. They found the SPN amplitude is the largest at the beginning of each block and then reduce with the experiment continuing. They proposed this effect was due to the amount of useful information that included in the first forth of trials was the largest and then the informativeness of later trials was decreasing dramatically.
Even though there was a great increasing in the number of studies on SPN, the origins of SPN is still unclear. The most prominent theory about the source of SPN is the right anterior insular cortex. Bocker and colleagues (1994) recorded a bilateral frontotemporal dipole during the activity between subjects’ response and feedback stimuli. In Brunia and coworkers (2000) study, they used PET technology found the activation of PFC, the temporoparietal insula reili and the parietal cortex. In addition, two fMRI studies conducted by Tsukamoto et al. (2006) and Kotani et al. (2009) also found the activation of right anterior insula underlie the occurrence of SPN, especially when right hemisphere preponderance also occurs.

In summary, all these three negativities I discussed above reflect the preparation of brain to the future activation according to the given stimuli. The BP is largely a movement related-potential, while the late CNV is both movement- and perception-related potential, and the SPN is a nonmotor-related anticipatory slow brain wave and can be enhanced with emotional stimuli.

**Lateralized Readiness Potential (LRP)**

The LRP, as its name indicates, is a negative lateralized slow brain wave. The LRP, as BP, can be observed over the motor cortex when subjects make response with one hand. But the distinctiveness of LRP from BP is that this motor cortex activation occurs only on the side that contralateral to the response hand rather than ipsilateral (Smulders & Miller, 2012). The timing of this component reflects the time point at which the brain starts to prepare for the motor movement.
The LRP is now widely used in psychological studies, especially studies that involve reaction time (RT). The reason why this component is so valuable is due to it is a relatively pure measurement in compare with other ERP components. The LRP can be isolated from other lateralized or unilateralyzed components by using a double subtraction technique (De Jong et al., 1988; Coles, 1989). This technique allows LRP maximally sensitive to the response hand in a unimanual response. It also cancels out lateralized activities unrelated with hand response, hand differences and all other overlapped components, such as N2 or P300. As a result, the first 200 ms of the waveform to isolate LRP is usually effectively zero (Smulders & Miller, 2012).

However, as typical, no method is perfect, there are still some nonmotoric noises that cannot be eliminated with the double subtraction technique. First of all, LRP will be contaminated by a lateralized somatosensory potential, if both presented stimuli and required motor response are in the same side of subject’s midline. Secondly, horizontal eye movements can also mix into LRP, especially when subjects try to look at their hands. The last and the easiest to be ignored is the lateralized contribution from reafferent activity after an overt response (Smulders & Miller, 2012).

LRP, as discussed above, is a widely interested and studied event-related component. It is not only used in studies about motor control in psychophysiology and neuroscience, but also in studies that are seeking for the answers towards various functional questions in cognitive psychology. Generally speaking, there are two main types: assessing motor preparation and partitioning the reaction time interval (Smulders & Miller, 2012).
On the aspect of assessing motor preparation, LRP is found to be useful in several types of studies. First of all, it is broadly used to understand movement preparation and organization. Many studies in this type employed the movement-precuing paradigm developed by Rosenbaum (1980), in which a cue signal was given to subjects in advance to let them prepare the designated hand to make corresponding response. By using this method, a clear LRP was produced after the cue signal (Leuthold et al., 1996) and this produced LRP can last steadily as long as 2 second while subjects were waiting for executing the cued response (Hackley & Miller, 1995). The size of this type of LRP depends on the amount of characteristically information provided by the cue signal (Smulders & Miller, 2012) and the complexity of the prepared response (Hackley & Miller, 1995).

Besides used on healthy subjects, LRP is also applied in studies to understand the deficits in motor preparation in some clinical population, such as Parkinson’s disease patients. LRP can be observed in both normal healthy subjects and Parkinson’s disease (PD) patients while preparing for a hand-specific motor movement (Mattox et al., 2006; Praamstra et al., 1998; Wascher et al., 1997), regardless the patients’ difficulty in motor execution. However, PD patients do need more time to prepare for the movements in compare with healthy subjects (Low et al., 2002; Wascher et al., 1997). The more complex the movements, the more time they need.

LRP is significantly associated with preparation of a motor movement, but the most interesting part is strong LRP can be observed even without an actual movement execution. Therefore, LRP are popularly used in detecting no overt movement-related partial preparation of motion (Smulders & Miller, 2012). This special characteristic of
LRP has been used as a powerful tool to address several important cognitive problems, such as, checking the existence of online response preparation in choice RT tasks (Eriksen & Eriksen, 1974; Gratton et al., 1988; Eimer, 1995); establishing models to understand the time point at which motor preparation begins (Miller & Hackley, 1992; Osman et al., 1992).

LRP is proven to be very useful on the aspect of assessing motor preparation regardless with or without overt movement accompanied, but LRP plays a more important role in partitioning the RT interval. In the general paradigm of eliciting LRP, a stimulus that signals the content of following motor response presents first. Then after a specific time period that depends on the study, subjects produce the signaled motor response. LRP can be observed during the delay period between the stimulus and the motor response. As discussed in previous sections, the occurrence of LRP reflects the preparation of a hand-specific motor movement. However, this hand-specific lateralization cannot be distinguished until the brain received the signal of stimulus and started to prepare for the response, therefore, the time interval between the signal stimulus and the onset of LRP (S -> LRP) can be considered as an index of the duration of stimulus processing. As the same matter of fact, the interval between the LRP onset and the response execution (LRP -> R) can be used as a measure of the duration of response and motor system preparation (Smulders & Miller, 2012).

This LRP involved RT partitioning system is used widely in varied of studies focus on many different topics, including precuing studies (e.g., Osman et al., 1995, Müller-Gethmann et al., 2000), speed-accuracy trade-off (e.g., Rinkenauer et al., 2004), temporal preparation (e.g., Müller-Gethmann, 2003), individual differences (e.g.,
Rammsayer & Stahl, 2007), psychological refractory period (e.g., Osman & Moore, 1993), additive factor method (e.g., Masaki et al., 2004; Low et al., 2002), Donders’ subtraction method (e.g., Smid et al., 2000), and so forth.

This LRP-based RT partitioning system helped researchers validate the notion that stimulus manipulation solely affect on the early perceptual stage but not the late response stage, which is influenced by the response manipulation (Smulders & Miller, 2012). Miller and colleagues (1999) manipulated stimulus intensity and found that their manipulation had a selective effect on the interval between stimulus and LRP, but not during the interval between LRP and response. Meanwhile, Smulders et al. (1995) also found a similar selective effect on early S -> LRP interval with manipulation of stimulus quality and they also found an effect of response complexity on the late LRP -> R interval. Their results also replicated by Low et al. (2002) on Parkinson’s disease patients.

The LRP partitioning system also helped confirm Rosenbaum’s parameter specification notion (1980). As Rosenbaum theorized that a pre-cue indicting some parameters about the required upcoming movement can speed the RT of response to a later imperative stimulus. He also concluded that the reason of this phenomenon is because the pre-cue provide specified parameters to motor system about the movement and reduce the time need for motor preparation. Therefore, according to his view, precuing should reduce the LRP -> R interval. This hypothesis did supported by later researches (e.g., Osman et al., 1995; Müller-Gethmann et al., 2000; Leuthold et al., 1996; Leuthold, 2003).
Besides helping researchers confirm and validate previously known theories, LRP partitioning system as well provides evidences to modify previous theories, such as in studies of understanding foreperiod effects or the speed-accuracy trade-off (SAT).

The foreperiod, a time interval between a warning signal and an imperative stimulus, has long been known to affect the response speed in a manner as: short foreperiod leads to faster response than long foreperiod when the foreperiod length is fixed within a block (Klemmer, 1956), and this effect was explained as a result of late motor speedup that is benefit from more motor preparation with short foreperiod (Sanders, 1983, 1998). This explanation suggested that the foreperiod effect should be on the duration of motor action, i.e., LRP -> R interval, but not on the S -> LRP. However, other researches provided incongruous evidences. They manipulated the foreperiod interval and found that their manipulations substantially affected the S -> LRP interval in all experiments, but the small degree effect on LRP -> R interval only occurred in half of the experiments (Osman & Moore, 1993; Jentzsch et al., 2007). Therefore, the effect of foreperiod manipulation, may be contrary to traditional view, is mainly on the perceptual stage.

The speed-accuracy trade-off (SAT) is a strategy of trading speed for accuracy that subjects use under varying levels of speed stress (Smulder & Miller, 2012). In order to be as accurate as possible, subjects need to adjust their premotor processes in order to achieve the trade-off between speed and accuracy. Therefore, the adjustment between faster but error-prone response and accurate but slower response should happen only before the motor response, i.e., the S -> LRP stage. However, according to previous studies (Osman et al., 2000; Van der Lubbe et al, 2001), this effect solely occurred during
the LRP -> R interval rather than S -> LRP interval. Even in studies that did get effects during S -> LRP intervals (Rinkenauer et al., 2004), main effects still found on the motor stage, which is contrary to the original theory.

Finally, with no surprise, this LRP based RT partitioning system also provides conclusion to some unsolved problems, such as the effects of accessory stimuli in a choice RT task. The accessory stimulus is a task-irrelevant stimulus that is presented together with a task-relevant stimulus and the occurrence of the accessory stimulus can reduce choice RT (Smulder & Miller, 2012). There were contrary theories about the accelerative effect of accessory stimulus on which stage of LRP. Posner (1978) theorized that the speedup effect of accessory stimulus is on the relatively early stage where perception and decision are formed. On the other hand, Sanders (1980) argued that the acceleration by accessory stimulus occurred during the late motor process. In order to solve these arguments, Hackley and Valle-Inclan (1998, 1999) did two studies to understand the effect of accessory stimulus by trying to identify the reduction of choice RT appeared on the early S -> LRP interval or late LRP -> R interval. In both studies, they found that the effect of accessory stimuli happened on the early perceptual S -> LRP stage, even when a portion of response selection shifted to the LRP -> R interval. Therefore, the LRP based RT partitioning system provided a conclusion to the accelerative effect of accessory stimuli: it affects only the early perceptual and decision-level processes.

To put all things in a nutshell, LRP, as an index of hand-specific motor activation, plays an important role not only in studies of psychophysiology, but also on cognitive psychology. It has been used in varied types of researches, especially in studies about
motor preparation and studies that involve reaction time. On the aspect of motor preparation, due to its special characteristics of being able to be detected regardless of with or without actual motor movement, LRP is one of the best tools to detect the occurrence and measure the duration of motor preparations. On the aspect of reaction time, the LRP based RT partitioning system separate the RT in to two essential parts, the S -> LRP interval and the LRP -> R interval. This partition isolates the RT into pure perceptual process and motor process. It provides researchers an alternative and accurate way to valid and confirm well-known theories, verify and offer new evidences to existing hypotheses, and test and correct previous conclusions.
Appendix B

Post-Error Slowing

Post-error slowing (PES) is a phenomenon in which people tend to slow down their response after making an error. It is traditionally theorized as a strategy to improve performance via a speed-accuracy trade-off (Laming, 1968). This explanation is less plausible when accuracy is instead reduced, as in the present ERP study.

Sixty healthy young adults performed a motor skill-learning task with varied feedback delays. On each trial, they were instructed by a visual display to make four brief, precisely timed key-press responses with a designated hand. After a short (2.5 s) or long (8 s) delay, feedback was given via a similar display. Response times increased (pooled mean RT from 908 ms to 965 ms, p < .01) and accuracy decreased (pooled mean accuracy from 96% to 94%, p < .001) on trials that followed an error in both delay conditions. No interaction was found. Also, the amplitude of SPN, an index of feedback anticipation, was found to be dramatically reduced after error trials. This suggests that subjects’ anticipatory processes in the current trial were compromised by negative feedback on the previous trial. These results are consistent with the theory of Notebaert, Houtman, et al. (2009) that, when errors are infrequent events, they orient subjects’ attention away from the task at hand.
Figure 9. Post-error slowing effect is found. The RT after an inaccurate trial is increased in compare with the RT after an accurate trial. In the legend, AI means an inaccurate response trial after an accurate response trial, AA means an accurate trial after an accurate trial, II means an inaccurate trial after an inaccurate trial, and IA means an accurate trial after an inaccurate trial.
Figure 10. The response accuracy of the trial after an inaccurate trial is reduced in compare with the accuracy after an accurate trial.
Figure 11. SPN for post-error slowing in short delay condition. AA and IA mean after an accurate and an inaccurate previous trial response, respectively.
Figure 12. SPN for post-error slowing in a long delay condition. AA and IA mean after an accurate and an inaccurate previous trial response, respectively.
Appendix C

ACADEMIC DELAY OF GRATIFICATION SCALE (ADDGS)

Below is a series of choices between two alternative courses of action. Please read each set of statements carefully, and relate each statement to this (Introductory Psychology) course. Then tell which course of action you would be more likely to choose and the strength of that choice. There are no right or wrong answers. Please respond with your true beliefs rather than the way you think you should respond. That is, tell us what you really would do under the conditions described in the statements. The answers that you provide are confidential; they will not be revealed to your instructor.

Please do this using the following scale:
(1) Definitely choose A
(2) Probably choose A
(3) Probably choose B
(4) Definitely choose B

1. A. Go to a favorite concert, play, or sporting event and study less for this course even though it may mean getting a lower grade on an exam you will take tomorrow,
   B. Stay home and study to increase your chances of getting a higher grade.

2. A. Study a little every day for an exam in this course and spend less time with your friends,
   B. Spend more time with your friends and cram just before the test.

3. A. Miss several classes to accept an invitation for a very interesting trip,
   B. Delay going on the trip until the course is over.

4. A. Go to a party the night before a test for this course and study only if you have time,
   B. Study first and party only if you have time.

5. A. Spend most of your time studying just the interesting material in this course even though it may mean not doing so well,
   B. Study all the material that is assigned to increase your chances of doing well in the course.

6. A. Skip this class when the weather is nice and try to get the notes from somebody later,
   B. Attend class to make certain that you do not miss something even though the weather is nice outside.

7
A. Stay in the library to make certain that you finish an assignment in this course that is due the next day,
B. Leave to have fun with your friends and try to complete it when you get home later that night.

8
A. Study for this course in a place with a lot of pleasant distractions,
B. Study in a place where there are fewer distractions to increase the likelihood that you will learn the material.

9
A. Leave right after class to do something you like even though it means possibly not understanding that material for the exam,
B. Stay after class to ask your instructor to clarify some material for an exam that you do not understand.

10
A. Select an instructor for this course who is fun even though he/she does not do a good job covering the course material,
B. Select an instructor for this course who is not as much fun but who does a good job covering the course material.
People differ in the ways they act and think in different situations. This is a test to measure some of the ways in which you act and think. Read each statement and indicate the most appropriate response. Do not spend too much time on any one statement. Answer quickly and honestly.

Four-point scale:
(1) Rarely/Never
(2) Occasionally
(3) Often
(4) Almost Always/Always

I plan tasks carefully.

I do things without thinking.

I make up my mind quickly.

I am happy-go-lucky.

I don’t pay attention.

I have racing thoughts.

I plan trips well ahead of time.

I am self-controlled.

I concentrate easily.

I save regularly.

I squirm at plays or lectures.

I am a careful thinker.

I plan for job security.

I say things without thinking.

I like to think about complex problems.

I change jobs.
I act on impulse.
I get easily bored when solving thought problems.
I act on the spur of the moment.
I am a steady thinker.
I change residences.
I buy things on impulse.
I can only think about one thing at a time.
I change hobbies.
I spend or charge more than I earn.
I often have extraneous thoughts when thinking.
I am more interested in the present than the future.
I am restless at the theater or lectures.
I like puzzles.
I am future-oriented.
Maslach Burnout Inventory (GS)

Please indicate how often you experience the following:

1 – Never, 2 – A few times a year or less, 3 – Once a month or less, 4 – Once a week; 5 – A few times a week, 6 – Every day

1) I feel emotionally drained from my work (studying).
2) I feel used up (like a “squeezed lemon”) at the end of the day.
3) I feel tired when I get up in the morning and have to face another day at work.
4) I can easily understand how clients, my subordinates and/or colleagues feel about things and try to keep their interests in mind when it comes to work.
5) I feel I treat some students/clients as if they were impersonal objects.
6) Working with people all day is a real strain for me and after work/studying I want to stay alone for some time.
7) I deal effectively with the problems of clients / I choose the right decision in conflict situations that arise during communication with my colleagues.
8) I feel depressed and apathetic / I feel burned out from my work/studying.
10) Lately, I’ve become more cold-hearted with those I work with / I have become more callous toward people since I took this job.
11) I worry that this job is hardening me emotionally.
12) I feel very energetic / I have a lot of plans for the future, and I believe I will accomplish them.
13) I feel frustrated by my job.
14) I feel I am working too hard on my job.
15) I don’t really care what happens to some clients, some of my subordinates and/or colleagues.
16) Working with people directly puts too much stress on me / I want to find a place to be alone in order to have a rest from everything and everyone.
17) I easily create an atmosphere of benevolence and collaboration within the collective.
18) During work I have a feeling of pleasant animation / I feel exhilarated after working closely with clients.
19) I have accomplished many worthwhile things in this job.
20) I feel like I am at the end of my tether.
21) In my work, I deal with emotional problems very calmly.
22) Every now and then I get the feeling that my colleagues or/and subordinates place their problems and tasks on my shoulders / I feel clients blame me for some of their problems.
Handedness Questionnaire

Instructions. For each of the activities below, please indicate:

Which hand you prefer for that activity? Do you ever use the other hand for the activity?

Which hand do you prefer to use when:

(1) Writing: Left / Right
(2) Drawing: Left / Right
(3) Throwing: Left / Right
(4) Using Scissors: Left / Right
(5) Using a Toothbrush: Left / Right
(6) Using a Knife (without a fork): Left / Right
(7) Using a Spoon: Left / Right
(8) Using a broom (upper hand): Left / Right
(9) Striking a Match: Left / Right
(10) Opening a Box (holding the lid): Left / Right
(11) Holding a Computer Mouse: Left / Right
(12) Using a Key to Unlock a Door: Left / Right
(13) Holding a Hammer: Left / Right
(14) Holding a Brush or Comb: Left / Right
(15) Holding a Cup while Drinking: Left / Right