Coll. Antropol. **36** (2012) 2: 513–520
Original scientific paper

Electrophysiological Correlates Activated During the Wisconsin Card Sorting Test (WCST)

Ana Havelka Mestrović[1], Marijan Palmović[2], Matija Bojić[2], Blanka Treselj[2] and Branimir Nevajda[3]

[1] University of Zagreb, Dubrava University Hospital, Department of Psychiatry, Zagreb, Croatia
[2] University of Zagreb, Postgraduate doctoral study Language and Cognitive Neuroscience, Zagreb, Croatia
[3] University of Zagreb, Dubrava University Hospital, Department of Neurology, Zagreb, Croatia

A B S T R A C T

In the present study we investigated changes in Event-Related Potentials (ERPs) during the Wisconsin Card Sorting Test (WCST) in order to identify cognitive processes underlying the set-shifting aspects of the task and to determine test sensitivity for frontal and prefrontal cortical areas. ERP's were recorded from a sample of 20 healthy adults while they performed a computerized version of the Grant & Berg (1948) version of the WCST, using 32-channel electroencephalogram recordings. The ERP waveforms were calculated for the set-shifting trials, or more precisely for the 2nd and the 3rd trials in the WCST series (set change condition) and compared to those associated with the last two trials in a series before the set change (set unchanged condition). The results indicated changes in central frontal and parietal electrodes during attentional set-shifting. More precisely, the P300 effect was replicated in this dataset, confirming the claim that the WCST measures function of prefrontal cortical areas of the brain. However, the obtained wave resembled P3b indicating the working memory component of the task. The results suggest that the frontal and parietal cortical activity is especially involved in set-shifting during WCST performance. Therefore, these electrophysiological results are not consistent with some recent studies that question the specificity of WCST as a measure of frontal and parietal lesions.

Key words: *Wisconsin Card Sorting Test, set shifting, event related potentials, P300, prefrontal cortex*

Introduction

Neuropsychological tests have been used for many years as the main technique to investigate cognitive and intellectual function. Over the last sixty years researchers have used these tests to determine which brain areas are involved in memory processes, cognitive control, and emotions. The developing technology of modern neuroimaging methods and the improvement of neuropsychological assessment instruments, correlates of cognitive function have been extensively investigated for the past twenty years. The prefrontal cortex (PFC) has long been thought to play an important role in cognitive control or the ability to orchestrate thought and action in accordance with internal goals[1]. The PFC is a collection of interconnected neocortical areas that sends and receives projections from virtually all cortical sensory systems, motor systems, and many subcortical structures. Neurophysiological studies in nonhuman primates have begun to define many of the detailed properties of the PFC, and human neuropsychology and neuroimaging studies have begun to provide a broad view of the task conditions in which it is involved[1]. The integrative theory of PFC function states that the PFC is not crucial in performing simple behaviours, such as unexpected sound or movement, that are relaying on so-called »bottom-up« processing. Instead, the PFC is important when »top-down« processing is needed or during intentional behaviour. The PFC is critical to establish the mappings between sensory inputs, thoughts, and actions that are not automatic, but controlled, and changing due to the demands of a given situation. Such situations require so-called »rules of the game«, internal representations of goals and the means to achieve them[1,2]. For over four decades, along with the Stroop task, the Wisconsin Card Sorting Test (WCST) has been one of the most distinctive tests of prefrontal function[3]. The WCST was originally developed in 1948 by Grant and Berg as a measure of learning, problem

Received for publication July 7, 2011

solving, abstract reasoning and response strategies to changing contextual contingencies[3,4]. Later, Milner (1963) demonstrated that the WCST is sensitive to frontal lobe lesions which lead to extensive use of this test as an index of frontal lobe executive dysfunction. There are several versions of the WCST available today, but in its standard form[5,6], a subject is asked to match a series of response cards containing geometric figures to four reference cards according to changing sorting principles. Geometric figures on response cards, as well as on reference cards, vary according to three attributes: colour, form and number[3]. Each of them defines the correct sorting category at varying time points during the test. During sorting, feedback is provided after each match indicating weather the participant used a correct or incorrect sorting rule. When subjects choose the correct rule they must maintain this sorting principle (or set) across changing stimulus conditions. After negative feedback they must change from the previously successful sorting rule and learn the new correct one. The correct sorting category changes without an announcement, after a fixed number of correct matches (usually after 10 consecutive correct responses). The correct sorting rule changes in two series from colour to shape and then to number. Since the participants do not know in advance that the rule is going to change, they must learn to change the sorting principles or shift set according to feedback[7]. Individual performance is assessed on tree main measures: the number of perseverative errors (i.e. when a subject continues to use the previously correct rule after receiving negative feedback), the number of nonperseverative errors, and the number of categories achieved (a category is achieved if a participant successfully matched 10 consecutive cards according to a correct sorting category)[3].

Successful WCST performance requires a number of cognitive functions: visual discrimination for comparison of the response cards to the referent ones; novelty detection; cognitive flexibility necessary for changing hypotheses or cognitive set-shifting and modification of a behavioural response set in accordance to changing contingencies; capacity for planning or hypothesis setting; maintaining the rule in working memory, as well as monitoring response accuracy; and inhibition of a previously correct task rule that governed behavioural responding[8,9] Early studies using the WCST showed worse performance in patients with frontal lobe lesions than in patients with lesions in other brain areas or healthy controls. Usually frontal lobe patients show more perseverative errors as well as fewer categories achieved indicating the impairment of executive function[3,7]. Many recent clinical studies replicate findings of early studies and point to poor WCST performance in patients with frontal cortex damage. However, the validity of the WCST as a test of exclusively frontal lobe dysfunction has been questioned in many studies. Some patients with frontal lobe lesions perform well on the WCST while some patients with lesions in non-frontal regions show poor performance[10] (Stuss et al., 2000). Thus, WCST performance appears to be impaired after damage to temporal, subcortical, hipoccampal and cerebellar regions[3]. Similarly, studies using neuroimaging techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) also have not shown consistent results and point to the WCTS's failure to discriminate patients with prefrontal lesions from patients with lesions in other areas of the brain[3]. As mentioned above, WCST performance includes many different abilities and for better understanding of WCST performance and brain structures that it engages, it is necessary to define and isolate specific cognitive processes included in WCST performance. Among many of them cognitive set-shifting is considered to be a crucial one[3,9,7] and is believed to rely upon dorsal prefrontal cortex (dPFC) activation[3]. Set-shifting is considered to be impaired in frontal lobe patients due to the inability to release attention from previously relevant perceptual dimension, and to re-engage in a new, previously irrelevant dimension[11] (Owen et. al, 1993). In the WCST set-shifting occurs when a sorting principle changes (i.e. from colour to shape) and subjects must shift their attention (set) from the previously correct sorting category to a new one. It is thought that the shift in cognitive strategies is essential while receiving feedback on the accuracy of sorting, especially in the case of negative feedback, while the other cognitive processes involved (i.e. updating information in working memory, inhibition of the previously correct rule, reasoning, decision making) likely occur after card presentation[12–14] Although neuroimaging studies have shown localization of activation, they have not been able to separate and precisely indicate when in the brain specific processes included in the WCST performance occur, due to their poor temporal resolution. The magnetoencephalogram (MEG) allows recording of brain activity in a millisecond timeframe along with relatively good spatial resolution. Using MEG[12], compared brain activity elicited by negative and positive feedback, and the presentation of cards following them. They found differences in brain responses to negative and positive feedback 460–640 ms after feedback presentation in the dPFC and the middle frontal cortex. Incorrect card matching elicited greater MEG activation than correct card matching in the dPFC, supramarginal gyrus, middle and inferior frontal gyrus (190–220 ms and 300–440 ms). Similar results were obtained in a MEG study by Periañez and colleagues[15] who found greater foci of activation during shift trials in the inferior frontal gyrus (100–300 ms), anterior cingulate cortex (200–300 ms and 400–500 ms) and supramarginal gyrus (300–400 ms and 500–600 ms). These results reveal activation in frontal and posterior areas involved with shifting and updating of information in working memory at different time points[3].

Similar to MEG, electroencephalography (EEG) also provides a continuous measure of brain activity in milliseconds, which is essential for analyzing the set-shifting that happens very fast. Scalp recorded Event-Related Potentials (ERPs) have been successfully employed as a method to explore fast brain dynamics underlying attention and working memory in humans[16] In ERP experi-

ments with the WCST the underlying component is the P300 (a positive wave with the maximal amplitude at 300 ms after stimulus presentation). The P300 component is one of the first event-related components reported in the literature but the research that followed has shown that it came in different flavours[17] Studies of the P300 have been based on different probabilities of stimuli and task relevance in various conditions, i.e. on the difference between rare and frequent stimuli in the oddball paradigm. Context-updating theory takes the P300 to be an index of brain activity related to the revision of the mental representations induced by incoming stimuli, i.e. an attention driven process of comparing the new stimulus with the one in working memory[18]. However, the context-updating model does not account for the results reported in paradigms with more than two stimuli. While the »classic« P300 (also called P3a) is obtained with a „deviant" stimulus in a sequence of frequent »normal« stimuli[19], if a third stimulus is added and the participant has to distinguish between the rare distracter and rare target stimuli to which he has to respond, a different waveform is elicited for the target stimuli, usually labeled P3b. As these results cannot be interpreted in terms of context updating, the resource allocation hypothesis[20] accounts for the differences in amplitude and latency depending on how demanding the task is (and, roughly, how much resources have to be allocated for the task). More demanding tasks reduce the amplitude and lengthen the peak latencies of the P300, which results in P3b in a more demanding three stimuli task. In standard ERP protocols frontal (P3a) and posterior (P3b) components of the P300 are described as two independent indices of attention processing – P3a is usually related to bottom-up, exogenous, stimulus-driven or involuntary processing of novel non-target distracters, and P3b as an index of top-down, endogenous or voluntary processing of target events[21]. Barceló[21] argues that those standard ERP protocols interpret any attention switches as involuntarily or exogenously generated by the non-target events. Since subjects need to respond to target stimuli and ignore any distracting stimuli that are not task-relevant, there is no actual shift in the attention set. So he proposes using dual-task or task-switching paradigms to explore ERPs to non-target events (such as feedback cues in the WCST protocol) that signal a voluntary attention shift. A cue prompting task-switching evokes a number of different executive processes that are known as task-set reconfiguration[22] after which a new task set must be maintained until the next switch is required[23]. In order to study these processes with the ERP technique Barceló and colleagues developed a task-switching paradigm, the Madrid Card Sorting Test[21,24–26] which overcomes some inadequacies of the standard WCST. Negative feedback in the WCST/MCST protocol that signals unpredictable shifts to a new task rule evoke frontally distributed P3a potentials (300–400 ms) and posterior longer latency P3b potentials (350–600 ms) sensitive to the task demands[21,24,25]. The authors suggest a differential role of these P300 components in cognitive set-shifting: frontal P3a as an index of switching (and reallocation of attentional resources to the new task set) and posterior P3b as an index of updating of task-sets in working memory.In this study we further investigated the ERP components underlying attentional set-shifting during WCST performance and explored the assumption that it relies on executive function of the frontal lobe. Larger ERP activation was expected during the set-shifting trials (early trials in the WCST series) than during the late WCST trials in which set maintaining is required. Also, we expected these differences in ERP activation to be larger in frontal compared to non-frontal brain areas. We decided to include healthy individuals with average results on cognitive tasks to examine ERP activity underlying WCST performance. This would provide control subjects for future investigation of the WCST performance and related ERP activity in neurological and psychiatric patients. This study is the first research in a Croatian population with these parameters and we decided to examine healthy subjects because they have a more homogeneous level of behavioural performance than clinical samples.

Subjects and Methods

Participants

Twenty healthy adults (mean age 28.1, SD 2.8, range 24–34 years), of both sexes (5 males, 15 females) took part in the experiments. They had equivalent levels of education and they were right-handed (right-handedness was tested with the Edinburg Handedness Inventory[27]. All participants had normal or corrected-to-normal vision. They had no history of psychological or neurological diseases, or drug abuse. All participants gave written informed consent approved by the ethical committee of PhD study in Language and Cognitive Neuroscience. The consent sheet contained detailed description of the course and purpose of the experiment. The participants received no money or credits for the participation in the experiment. The dataset of one participant was not used in the analysis due to the large artefacts caused by skin potentials.

General procedure

The participants were invited to the electrophysiological laboratory, where the event-related potentials during the WCTS were measured. The preparation procedure (placing the electrodes, the instructions) lasted 20 minutes, after which the participants were comfortably seated in an electromagnetically shielded booth. The test lasted between 10 and 15 minutes, depending on the participant (there was no time limit for the participant to press the response button that triggered the program to show the feedback and the new card). Participant should answer with right hand if they want to press right button and with left hand for left button. Finally, the procedure of removing electrodes lasted 5 minutes. After each experiment, the participants were shown their results regarding the behavioural performance on the test.

Stimuli

The computerized version of the WCST was used, provided by NeuroStim Inc (CARDSORT), version of Berg and Grant, 1948, which was designed to test »abstract behaviour« and »shift of set«[28]. It is an integral part of the stimulus presentation software of the NeuroScan NuAmps EEG amplifier and NeuroScan audio-video stimulator (Stim II software). The software allows for manipulating some of the features of the test: number of trials and rule-change conditions. In this experiment the rule changed after 10 correct responses and each condition (colour, form and number) was given ten times.

In each trial a single choice card was presented at the right bottom corner of the screen and the subject had to match it to one of the four reference cards that remained displayed on the upper part of the screen. The screenshot of the stimuli is given in Figure 1. Immediately after the response, written positive or negative feedback was provided depending on whether the matching was correct or incorrect. The feedback appeared on the upper centre part of the screen in white letters on the black background. At the same time a new choice card was presented starting a new trial. The monitor was located 1.5 m in front of the subject and each card formed an angle of 1.26 high and 1.19 wide[28].

Participants were asked to match the choice card in each trial with one of the four reference cards by pressing the corresponding button on the response box (the far left button for the far left card, far right button for the far right card and so on). Unlike the original WCST procedure, participants were instructed of the three possible sorting rules, and that the correct rule would change from time to time without prior notification, and that they would have to change their response rule according to the provided feedback. Participants performed the WCST with the criteria (colour – form – number) changing in random order. There was no time limit for choosing the place for the given card. The feedback (»Correct« or »Incorrect«) was given immediately after the response, above the four cards. Prior to EEG recording, participants practiced the task for about 5 minutes to ensure that they had understood the instructions and to reduce their anxiety

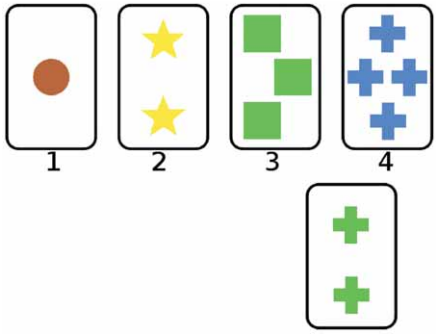

Fig. 1. The screenshot of the test with the 4 presented cards (upper row) and one response card (lower). The card can be »placed« under 2 (number criterion), 3 (colour criterion) or 4 (form criterion). These criteria changed after ten cards were presented and were unknown to the participants.

Data Analysis

The EEG signal was recorded with the 36 canal NeuroScan NuAmps amplifier with a sampling rate of 1 kHz. It was corrected for ocular artefacts, filtered with a low pass filter of 30 Hz and high pass filter of 0.01 Hz. Due to a large amount of artefacts, data from one participant were excluded from further analyses. For the remaining 19 participants the signal was averaged in the interval –100 to 1000 ms around the stimuli (the moment of the presentation of the feedback and the new card). Brain Products' Vision Analyzer was used to obtain the averaged waveforms and topographic distribution.

Since set-shifting occurs after the negative feedback, which follows incorrect matching of the first card in a new set, there is a 50% chance that the participant would correctly match the card in the second trial (since there are two new possibly correct rules). If they match the card incorrectly, negative feedback is provided again, and in the third trial healthy subjects should match the card according to the one remaining rule which proves to be correct one. Participants then maintain that rule, i.e. they continue to match cards according to that rule in the remaining trials of the set, and each match is followed by the positive feedback. Accordingly, 2nd and 3rd trials of the WCST series were averaged together as set-shifting trials into set change WCST waveforms (criterion change condition), and the last two trials were averaged together into set unchanged WCST waveforms (criterion unchanged condition).

A three-way repeated measures Analysis of Variance (ANOVA) with condition (set change *vs*. set unchanged), lobe (3 levels: frontal, central and parietal) and hemisphere (3 levels: left, middle and right) for the mean ERP amplitudes in the time interval of 250–350 ms since the predicted frontal activity associated with set-shifting is expected to fall in this interval (P300) was used to explore the predicted frontal activity associated with set-shifting trials.

Results

Grand averages of 19 participants show a clear P300 component on the relevant frontal and central electrodes (Figure 2). The slow P3 wave and its long latency indicate the P3b component[29].

The distribution of the P300 is frontal, parietal and central as shown on the topographic maps (Figure 3). The maps are based on the difference wave, i.e. the difference in the amplitudes between the two conditions (cond. 2 (set-change) – cond. Set unchanged 1). The maps clearly show that the activity reaches its peak in the 200–300 ms interval (e. g. at 218 ms at the Cz electrode), lasts for about 200 ms (200–400 ms) and that the P300 effect fades out between 500 and 600 ms.

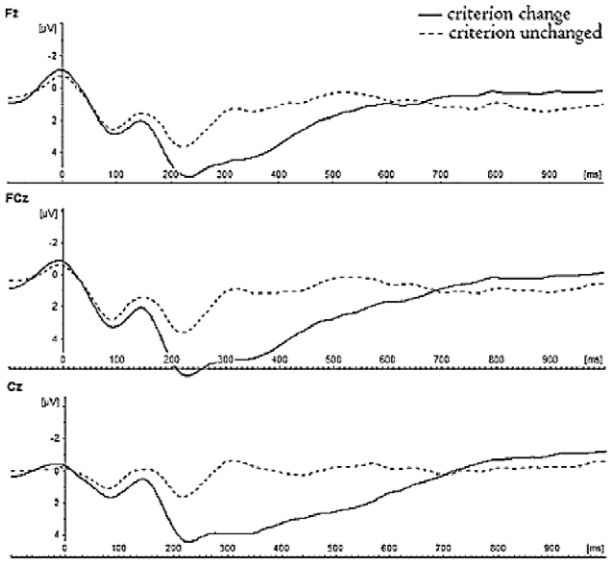

Fig. 2. The difference in amplitude of the P300 between set change WCST trials (criterion change condition) and set unchanged WCST trials (criterion unchanged condition) (positivity is plotted downwards).

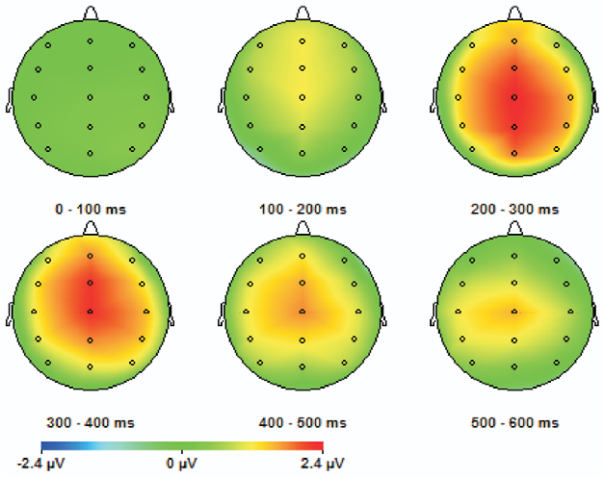

Fig. 3. Topographic distribution of the P300 (difference wave).

The results were statistically analysed using repeated measure ANOVA with three within-group factors: Condition (set change *vs.* set unchanged) Lobe and Hemisphere. Since Lobe and Hemisphere factors are 3-level factors (Frontal-Central-Parietal and Left-Middle-Right, respectively) the data were analysed in a 2×3×3 matrix. The mean amplitude in the relevant time interval (250–350 ms after the feedback and new stimulus presentation) was taken as the dependent variable on 9 electrodes in order to cover all relevant lobes and hemispheres (F7, Fz and F8 for the frontal lobe, T3, Cz and T4 for central electrodes (where T3 and T4 were positioned above left and right temporal lobes, centrally) and TP7, Pz and TP8 for parietal lobe (again, TP7 and TP8 were positioned above temporo-parietal regions). The analysis applied here is common for ERP studies and is recommended in Luck (2005). The overall results (F-values and significance levels) are shown in Table 1.

The analysis showed that there is a significant main effect of the condition (set change *vs.* set unchanged). The post hoc test (Duncan) showed that the effect was significant over the middle and right hemispheric electrodes, but only centrally and parietally and on the middle frontal electrode (Fz). Both main effects of lobe and hemisphere proved to be sigificant, which means that the effect is constrained to particular (mainly middle and right, central ad parietal) topographic locations (EEG does not provide brain localization data). This analysis is consistent with the distribution map of P300 (Figure 3) showing a broad central positive peek around 300 ms with a slight right hemisphere maximum. The interaction between condition and lobe factors was not found to be significant and the condition*hemisphere interaction can be regarded only as marginally significant.

TABLE 1
THE ANOVA RESULTS OF THE WCST EXPERIMENT

Effect	SS	df	$\overline{X}$	F	p
Condition	22.8	1	22.8	15.20	0.001*
Lobe	107.2	2	53.6	12.90	0.000*
Hemisphere	764.2	2	382.1	30.36	0.000*
Cond*Hemisphere	22.2	2	11.1	2.68	0.083

SS: sum of squares, df: degrees of freedom, $\overline{X}$: mean squares, F: F-values and p: significance (*) at the <0.05 level

These results are graphically represented on Figure 4. While the left graph corresponds to the broad distribution of the P300 effect over frontal (significant only on Fz), central and parietal areas, the graph on the right side shows a slight right hemispheric dominance in this task (more positivity over the middle and right hemispheric electrodes, the biggest effect, i. e. the difference between experimental conditions on the right hemispheric electrodes). However, with the condition*hemisphere interaction p=0.083, these results can be regarded as marginally significant, at best.

Discussion

The aim of this research was to examine by using ERP techniques whether the WCST, which has been used for more than 40 years in clinical and experimental psychology, actually measures executive function of the frontal lobe. Our results demonstrate larger P300 amplitudes associated with early WCST trials when set-shifting occurs compared to late WCST trials when participants need to maintain the previously chosen sorting rule. The obtained P300 component resembles P3b, which is interpreted as reflecting working memory and memory storage processes[3,21,23]. Namely, during the task the participants have to memorize the sorting rule. Working memory is localized in prefrontal, parietal and frontal region

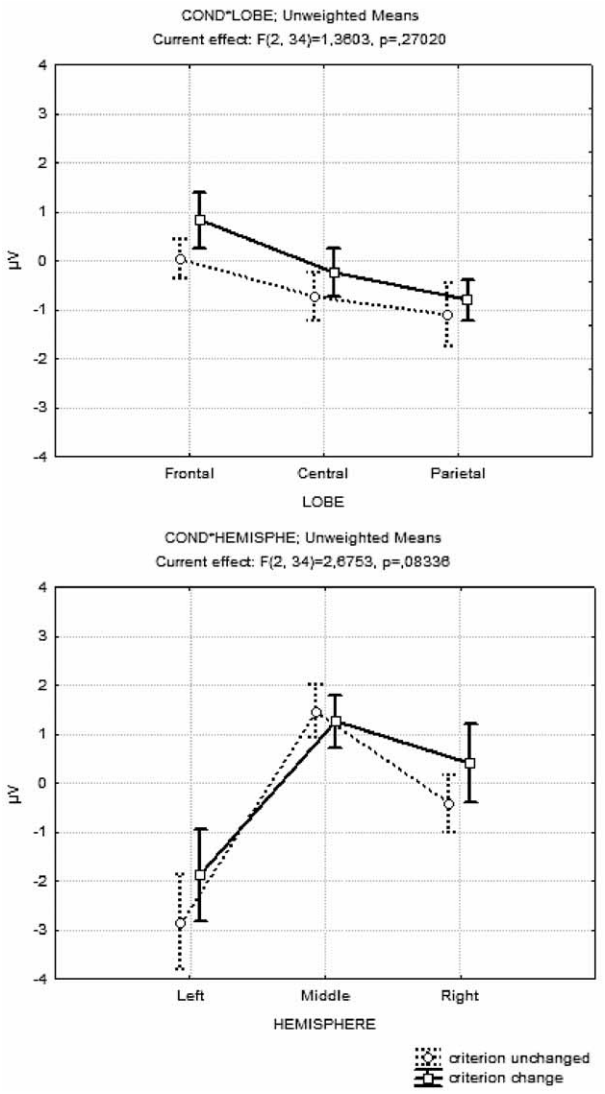

Fig. 4. Mean amplitudes in the 250–350 ms interval.

(hippocampus region), and our results show a working memory component during the execution of the task. Our results are consistent with previous findings in studies that explored ERP activity related with the WCST performance. In an earlier study with healthy volunteers performing a WCST variant, namely the Madrid Card Sorting Test (MCST), Barceló and colleagues[7] compared ERP responses associated with process of searching and shifting attention to a new sorting rule during early trials (2nd and 3rd) in the WCST series (extra dimensional shifts) and to the process of maintaining attention to the relevant category in late trials (6th and 7th) towards the end of the series (intradimensional shifts). They found a stronger negative field potential (120–180 ms) at the left fronto-temporal region during early WCST trials and suggested that it might reflect the activation of the left dPFC. Both early and late WCST trials elicited the P3a component (300–350 ms) over frontal areas but there were no task effects on its amplitude or latency, which the authors explained as an index of attention orienting to every new sorting card in the series. Also, they found that both early and late WCST trials elicited large P3b waves (350–450 ms) over posterior regions although its amplitudes were larger during late WCST trials, probably reflecting context-updating process (updating of the memory representation). In another study[24] the authors demonstrated a gradual build-up during post-shift trials (i.e. when subjects need to maintain a successful rule), in addition to a decrease in P3b amplitude over posterior association cortices during early WCST trials in which set shifting occurs. Since it was not observed when the new rule was externally prompted in a control task, the authors concluded that the reduction in the P3b amplitude was related to an endogenously generated shift in the perceptual rule used to sort cards, and that its gradual build-up represents reconfiguration of the attention set i.e. stimulus-response mappings in working memory. Although they reported significant changes in P3b associated with the set or attentional shifting, the results in the above studies differ from those obtained in our study. In contrast to our results that show a larger P3b amplitude during set-shifting trials (i.e. when the rule or criterion according to which cards need to be sorted is changed) compared to trials in which subjects need to maintain the rule, and the criterion remains unchanged, Barceló and colleagues found a reduction in P3b amplitude for set-shifting trials and its increase towards the end of the WCST series. This can be explained by the fact that in the earlier studies by Barceló and colleagues ERPs were calculated time-locked to the presentation of a new card and not to feedback events when set-shifting is hypothesized to occur. Unlike the MCST used in the above described studies that allows separating the occurrences of different WCST events over time, the WCST version that was used in this study does not allow this. More precisely, in the version that we used, after the participant pressed the button in order to match the response card to the chosen reference card, feedback was immediately provided and at the same time a new choice card was presented. Thus, it was impossible to separate ERP activity related to feedback and card presentation events. However, based on later studies of ERP components related to WCST performance, we believe that our findings of increased P3b amplitude in the early, set-shifting WCST trials was associated with the negative feedback event that prompted subjects to change the task set. Thus, in later studies, Barceló and colleagues[30,31] measured ERP responses to contextual cues time-locked to feedback events and to target events time-locked to the card-matching stage of WCST performance. This revealed a number of ERP components related to various cognitive processes involved in set-shifting or task-switching. Feedback cues signalling unpredictable shifts to a new task rule (i.e. negative feedback) evoked frontally distributed P3a potentials (300–400 ms). It has to be noted that although this cue was the same in all shift trials, the P3a amplitude did not diminish over successive task blocks. So, in addition to its relation to bottom-up processing of novel non-targets under a fixed task-set, it could also be

related to top-down or voluntary attention control. In our study, this P3a component was not obtained, probably due to the problems of the WCST version that we used mentioned above. However, feedback cues also evoked longer latency P3b potentials (350–600 ms) that were sensitive to the number of rules held in memory (greater P3b amplitude in tasks with three rules than two) and to the subject's ability to predict the next task rule (decrease in P3b amplitude between first and second feedback cues that signalled maintenance of the chosen rule i.e. positive feedback). These results, although more extensive, are congruent with our findings of decreased P3b amplitude in late WCST trials or the set unchanged condition when participants need to maintain the chosen rule. Barceló and colleagues[21,30,31] interpreted these two P300 components as representing different components in cognitive set-shifting: frontal P3a as an index of switching (and reallocation of attentional resources to the new task set) and posterior P3b as an index of updating of task-sets in working memory. Differences in scalp distribution and intensity of ERP components between early and late trials in the WCST, i.e. between extra- and intra-dimensional set shifts are considered to reflect activation of a category representation in working memory along with inhibition of the previous category that occurs during set-shifting[3,16,31]. Other ERP components are related to and modulated by processes that occur before and after set shift such as task-set maintenance over trials and task-set implementation at card onset[3].

The P3b effect obtained in this study reflects increased working memory processing related to set-shifting or task-shifting. However, the limitations of the stimulus presentation software (simultaneous presentation of the new card and the feedback for the previous one) and only one ERP component obtained, do not allow for more fine grained temporal analysis of the processes involved in the WCST. On the other hand, the fact that the P3b component has been obtained even with the original WCST supports the robustness of the processes involved and make the WCST a suitable tool for studying attention and memory processes. In addition to ERP studies that demonstrate both frontal and posterior distribution associated with set-shifting, numerous neuroimaging studies also point to widespread brain activation associated with WCST performance. The vast majority of these studies report increased activation in prefrontal regions, especially in dorsolateral prefrontal cortex (DlpFPC) but activation is also reported in the ventromedial prefrontal cortex (vmPFC), and the orbitofrontal cortex (OFC). The laterality of this prefrontal activation is still not clear. However, these studies have also shown the activation of the inferior parietal lobes, temporo-parietal association cortex, as well as in the primary and secondary association visual cortices. In some studies activity was also found in the mid-thalamus, the basal ganglia, the parahippocampal gyri, and the hippocampus proper[3,7]. However, these studies didn't isolate brain activity related especially to set-shifting events during WCST performance, so it is not clear which specific cognitive processes increased activity in particular brain regions.

Konishi[32] used an event-related fMRI method to capture brain activation as a consequence of set-shifting in a computerized version of the WCST, since fMRI allowed them to isolate and localize this component of the test. They found shift-related activation in the posterior part of the bilateral inferior frontal sulci and explained it as the updating contest of working memory and, possibly, response inhibition function. In addition to the prefrontal activation, they found a lesser amount of set-shifting related activity in the parietal cortex, bilateral supramarginal gyri and the anterior cingulate cortex. Similarly, in another fMRI study using an adapted task design, Monchi et al.[9] compared brain activity associated with the receiving of feedback and card matching. Results demonstrated increased activity in the mid-dPFC in response to either positive or negative feedback when current information was compared to earlier events stored in working memory[33–35]. Beside this, the mid-vPFC, caudate nucleus, and mid-dorsal thalamus showed increased activity associated specifically to the negative feedback. Furthermore, increased activity in the left putamen, left posterior PFC, posterior parietal cortex, prestriate cortex and right lateral premotor cortex was associated to card matching after negative feedback, while the lateral premotor cortex, bilaterally, and the left posterior parietal cortex showed increased activity associated to card matching after positive feedback[33,34]. It appears that set-shifting is not exclusively related to frontal lobe activity, but includes posterior areas. This posterior activity may be reflected in the P3b component obtained in our study.According to an integrative theory of PFC, visual information takes a circuitous route, traveling from the opposite inferior temporal (IT) cortex to the ipsilateral PFC in each hemisphere and then down to the »blind« IT cortex. This was confirmed by severing the PFC in the two hemispheres and eliminating the feedback, which abolished the IT activity and disrupted task performance. Therefore, the results of our study are in accordance with the above integrative theory of PFC since they show greater activity in right hemisphere while performing the set-shifting tasks. However, the EEG is not a reliable method for the localization of brain function.

Future studies of ERP activity underlying the WCST performance should include comparisons of different age groups to determine age-related changes in the cortical activity associated with set-shifting processes as well as comparison of healthy subjects to psychiatric and neurological patients to investigate how specific impairments affect these cognitive processes.

Conclusions

In this study we have shown that the WCST can be used in neuropsychological practice as a valid instrument for measuring prefrontal and frontal cognitive function such as attention, judgment, decision making and work-

ing memory. The results reveal a significant P300 effect by manipulating the novelty of the sort criteria. The strongest P300 effect was obtained frontally over the right hemisphere and medially which corresponds to other studies. Current models of cognitive control point to the significant role of the prefrontal cortex in »top--down« processes, which include voluntary attention and control, and reasoning abilities. The results of our study confirm the involvement of frontal and prefrontal regions in shifting the set of thinking. However, the broad latency of the P300 (P3b) implies involvement of other brain regions in temporal-parietal areas. Future research should include different age groups, e.g. young children vs. adults to show maturational changes which should be most prominent in the frontal regions.

REFERENCES

1. MILLER EK, COHEN JD, Annu Rev Neurosci, 24 (2001) 167. — 2. PASSINGHAM RE, The frontal lobes and voluntary action (Oxford university Press, New York, 1993). DOI:10.1146/annurev.neuro.24.1.167 — 3. NYHUS E, BARCELÓ F, Brain Cogn, 71 (2009) 431. — 4. GREVE KW, INGRAM F, BIANCHINI KJ, Arch Clin Neuropsych, 13 (1998) 597. DOI: 10.116/j.acn.2004.09.004 — 5. HEATON RK, Psychological Assessment Resources (Odessa Inc, Florida, 1981). — 6. HEATON RK, CHELUNE GJ, TALLEY JL, KAY GG, CURTISS G, Psychological Assessment Resources (Odessa Inc, Florida, 1993). — 7. BARCELÓ F, Span J Psychol, 4 (2001) 79. — 8. CORKIN S, Trends Cogn Sci, 5 (2001) 321. — 9. MONCHI O, PETRIDES M, PETRE V, WORSLEY K, DAGHER A, J Neurosci, 21 (2001) 7733. — 10. STUSS DT, LEVINE B, ALEXANDER MP, HONG J, PALUMBO C, HAMER L, MURPHY KJ, IZUKAWA D, Neuropsychologia, 38 (2000) 388. — 11. OWEN AM, ROBERTS AC, HODGES J R, SUMMERS BA, POLKEY CE, ROBBINS TW, Brain, 116 (1993) 1159. — 12. WANG L, KAKIGI R, HOSHIYAMA M, Cogn Brain Res, 12 (2001) 19. — 13. BARCELÓ F, KNIGHT RT, Neuropsychologia, 40 (2002) 349. — 14. BARCELÓ F, ESCERA C, CORRAL MJ, PERIÁÑEZ JA, J Cogn Neurosci, 18 (2006) 1734. — 15. PERIÁÑEZ JA, BARCELO F, Neuropsychologia, 6(2009) 1254. — 16. BARCELÓ F, Brain Research Protocols, 11 (2003) 27. — 17. SUTTON S, BRAREN M, ZUBIN J, JOHN E, Science, 150 (1965) 1187. — 18. DONCHIN E, Psychophysiology, 18 (1981) 493. — 19. FABIANI M, GRATTON G, FEDERMEIER KD, The Handbook of Psychophysiology (Cambridge University Press, Cambridge, 2007). — 20. VERLEGER R, Behav Brain Sci, 34 (1998) 154. — 21. BARCELÓ F, PERIÁÑEZ JA, KNIGHT RT, Neuroreport, 13 (2002) 1887. — 22. MONSELL S, Trends Cogn Sci, 7 (2003) 134. — 23. FRIEDMAN D, NESSLER D, JOHNSON R, WALTER R, BERSICK M,Aging, Neuropsychology and Cognition, 15 (2007) 95. DOI: 10.1080/13825580701533769 — 24. BARCELO F, SANZ M, MOLINA V, RUBIA FJ, Neuropsychologia, 35 (1997) 399. — 25. BARCELÓ F, Neuroreport, 10 (1999) 1299. — 26. BARCELÓ F, MUNOZ--CESPEDES JM, POZO MA, RUBIA FJ, Neuropsychologia, 38 (2000) 1342. — 27. OLDFIELD RC, Neuropsychologia, 9 (1971) 97. — 28. Stim2 User Manual, Cognitive and Neuropsychological Tasks (CompuMedics NeuroScan, Texas, 2003). — 29. POLICH J, Clin Neurophysiol, 118 (1992) 2128. — 30. BARCELO F, RUBIA FJ, Neuroreport, 9, (2002) 747. — 31. BARCELÓ F, KNIGHT RT, Cereb Cortex, 15 (2007) 51. — 32. KONISHI S, NAKAJIMA K, UCHIDA I, KAMEYAMA M, NAKAHARA K, SEKIHARA K, MIYASHITA Y, Nat Neurosci, 1 (1998) 84. — 33. MILLER, E. K. Nat Rev Neurosci, 1 (2000) 59. — 34. MILNER B, Arch Neurol, 9 (1963) 100. — 35. BELLEVILLE S, CHERTKOW H, GAUTIER S, Neuropsychology, 21 (2007) 458.

A. Havelka Meštrović

University of Zagreb, Dubrava University Hospital, Department of Psychiatry, Av. Gojka Šuška 6, 10000 Zagreb, Croatia
e-mail: ana.havelka@zvu.hr

ELEKTROFIZIOLOŠKI KORELATI KOGNITIVNIH SPOSOBNOSTI TIJEKOM RIJEŠAVANJA WISCONSIN TESTA SORTIRANJA KARATA (WCST)

SAŽETAK

U provedenom istraživanju ispitivali smo promjene u elektrofiziološkom odgovoru tehnikom evociranih potencijala (ERP) tijekom rješavanja testa sortiranja karata kako bi pokazali koji kognitivni procesi su u podlozi promijene seta mišljenja i uvidjeli koliko je test zaista osjetljiv na promijene u frontalnim i predfrontalnim regijama korteksa. Evocirani potencijali su mjereni kod 20 zdravih odraslih osoba koje su bile dešnjaci tijekom računalnog rješavanja WCST-a (verzija Grant i Berg, 1948). Snimanje je provedeno sa 32 kanalnim elektroencefalografom. Otklon evociraniog potencijala mjeren je tijekom promjene seta mišljenja, točnije u drugom i trećem odgovoru na testu i uspoređivan je sa zadnja dva prethodna odgovora (promjena seta mišljenja/bez promjene seta mišljenja). Rezultati ukazuju na promjene u centralnim i parijetalnim elektrodama tijekom promjene seta mišljenja, odnosno usmjeravanja pažnje. Točnije, P300 efekt je dobiven što nam upućuje da WCST zaista mjeri funkcije predfrontalnih struktura korteksa. Nadalje, P3b amplitude nam ukazuje i na mjerenje radnog pamćenja tijekom rješavanja testa sortiranja karata. Zaključno, rezultati upućuju na frontalnu i parijetalnu kortikalnu aktivnost tijekom promjene seta mišljenja na testu sortiranja karata. Elektrofiziološki rezultati nisu konzistentni s prethodnim istraživanjima koja proučavaju ovu karakteristiku testa sortiranja karata kao pokazatelja frontalnih i parijetalnih lezija.