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Neurophysiological correlates of cognitive flexibility and feedback processing in violent juvenile offenders

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ABSTRACT

The persistence of aggressive criminal behavior is recurrently observed in offenders despite being previously advised on the negative consequences of their actions. One possible explanation for the continuation of aggressive behaviors could be that they are the consequence of either possible deficits in cognitive flexibility (set-shifting) or in altered feedback processing. Event-related brain potentials (ERPs) were used to investigate both processes in non-psychopathic violent juvenile offenders. A modified version of the Wisconsin Card Sorting Test (WCST) was used to disentangle the ERP components associated with cognitive set-switching processes (P3) from feedback processing (Frontal-Related Negativity, FRN; P3). The results showed a reduction in the amplitude of the P3 component for the presentation of switch informative signals, related to set-switching processes, in the offender group. Interestingly, a larger amplitude of the P3 related to feedback processing as well as the FRN was observed in this population, probably indicating increased reliance on external feedback processing. At the behavioral level, the offender group presented a larger amount of issues with failures in implementing the new sorting rule. This behavioral pattern could be related to deficits in the ability to switch to another behavior and an altered pattern in processing the feedback information related to the precision of their performance. These observations highlight the possible role of cognitive set-switching and reward sensibility in the maintenance of harmful behaviors in juvenile offenders.

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1. Introduction

A significant proportion of offenders persist in their aggressive and criminal behavior regardless of being advised about the possible negative consequences of their actions, this continues to occur despite the investments in delinquency rehabilitation programs (Greenwood, 2008). One possible explanation is that criminal offenders are impaired in their ability to use environmental feedback-related signals in a flexible manner in order to socially adapt and regulate their behavior. The accommodation of information coming from different sources in a flexible manner is related to what is known as high-level metacognitive and cognitive control functions, which refers to a range of cognitive processes that subserve goal-directed behavior, such as planning, problem-solving, cognitive flexibility, inhibition, working memory and performance monitoring (Luria, 1966; Shallice, 1982; Damasio, 1995; Grafman and Litvan, 1999; Burgess et al., 2000; Miyake et al., 2000; Miller and Cohen, 2001; Lehto et al., 2003; Braver and Hannes, 2005; Huizinga et al., 2006; Fuster, 2014).

In clinical neuropsychology one of the most frequently used tasks to assess cognitive control is the Wisconsin Card Sorting Test (WCST; Grant and Berg, 1948; Heaton et al., 1993). The WCST requires participants to flexibly adapt their behavioral responses to simple geometrical stimuli on the basis of signals provided by the experimenter (Milner, 1963; Stuss and Picton, 1978; Heaton, 1981; Heaton et al., 1993; Braver and Hannes, 2005). In the traditional versions (WCST; Grant and Berg, 1948; Heaton et al., 1993), participants have to infer the current rule about three possible sorting rules (color, shape, or number), on the basis of positive (correct) and negative (incorrect) feedback provided by the examiner after each choice. In order to respond correctly, participants have to match the target card (with a specific color, shape and number) with one of the four key cards (each one with one different color, shape and number). When participants discover the new correct rule, they have to maintain it, however after some trials, the sorting rule changes again, requiring participants to find the new correct sorting rule.

The WCST is commonly used as an index of perseveration, which is understood to be the persistence in responding to the previous rewarded choice, which is currently no longer rewarded (Heaton et al., 1993). Two abilities are crucial to correctly perform the task (Huizinga and van der Molen, 2007):

(i) *Set-switching abilities*, indexed by either the errors occurring when a participant fails to switch to another sorting rule (perseverative errors) after receiving the feedback indicating a switch from the previous trial (Heaton et al., 1993).

(ii) *Set-maintenance* ability, which is evaluated by measuring non-perseverative errors (set-maintenance errors), involving occasional failures to maintain the chosen, correct rule. Several functional neuroimaging studies using the WCST have revealed the activation of a widely distributed brain network encompassing several prefrontal regions (i.e., inferior frontal gyrus, dorsolateral prefrontal cortex, anterior cingulate cortex) and posterior association areas (i.e., supramarginal gyrus, intraparietal sulcus) when task sets need to be changed (Nagahama et al., 1997; Volz et al., 1997; Monchi et al., 2001).

Despite the apparent perseverative behavioral tendencies observed in the offender population, and the frequent use of the WCST in the clinical population, there are few investigations which have used this task to assess offenders performance without the presence of psychopathy. Interestingly, initial studies revealed no differences between non-psychopathic offenders and healthy controls. For example, Gorenstein (1982) showed a larger amount of perseverative errors in psychopathic offenders, but not in non-psychopathic offenders when compared to control participants. Likewise, Appellof (1985) did not encounter lower performance in juvenile offenders when compared to controls using the WCST. More recently, however, several studies have reported the first evidence of existing differences between juvenile offenders and controls, with the former group showing more perseverative errors (Syngelaki et al., 2009). In a similar vein, Van Goozen et al. (2004) using the Door Opening Task (DOT; Daugherty and Quay, 1991; Matthys et al., (1998)), a task related with the sensitiveness to reward, found that children classified with conduct disorder incurred more perseverative responses than control participants, despite this behavior being less efficient in terms of monetary gains. These authors considered that this pattern indicated an altered inhibitory function in conduct disorder children under conditions in which a monetary reward was presented. In a more recent study, Dolan (2012) showed a set-switching dysfunction in a population of offenders, compared to controls, and importantly, this dysfunction was not associated with the extent of their psychopathic traits, indicating that it could not possibly be related to psychopathy. Overall, although the results are not completely clear or concordant across studies (Tuominen et al., 2014), this review of the existing literature suggests that offenders might have several difficulties at a cognitive level that might explain their non-adaptive behavior.

Even though the WCST has been commonly considered to be associated to perseverative behavior (Heaton et al., 1993), the encountered results in offenders are difficult to interpret because of differing executive functions, e.g., set-switching, inhibition, etc. Working memory capabilities have also been identified as contributing to performance in this task (Ozonoff, 1995; Miyake et al., 2000). One way to better elucidate the different cognitive control processes involved in WCST and which may be altered in juvenile offenders is by using fine-grained electroencephalographic measures (Event-Related Brain potentials, ERPs) (Barceló et al., 2002; Cunillera et al., 2012). In the current study, and for a selected sample of violent juvenile offenders, we evaluated their performance in a modified ERPs version of the WCST (Cunillera et al., 2012), which allows us to disentangle the role of *set-switching* (rule-based behavior) and *feedback processing* (outcome-based behavior), in the same task (see Figs. 1A for task illustration), two processes with results that are typically entangled in the WCST. Thus, in this version of the task, two types of signals are separately presented to participants: (i) cue signals: indicating whether to either *repeat* the same sorting rule or *switch* to another rule at the beginning of each trial; and (ii) *feedback signals*: appearing after the participants' response, indicating

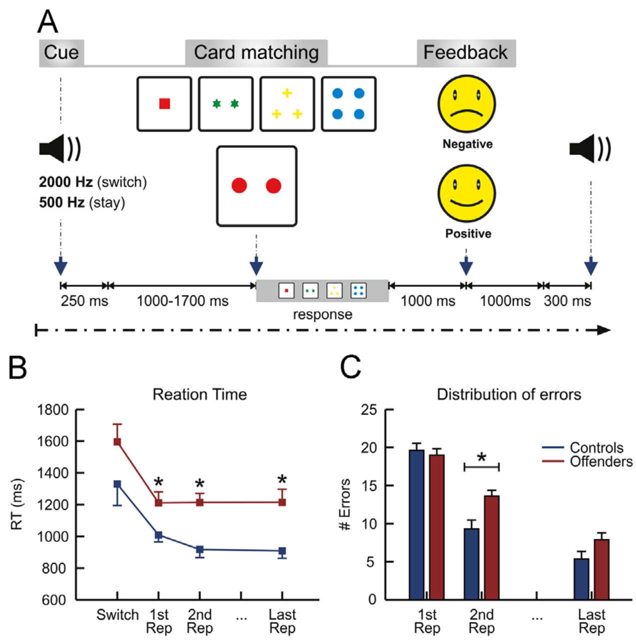

Fig. 1 – Task illustration and behavioral results.
(A) Schematic illustration of the trial structure in the modified version of the Wisconsin card sorting test (WCST) including the feedback signal. Participants were instructed to match a target card, centered on the computer screen, with one of the four key cards located on top by following one of the three possible sorting rules: number, color, or shape of elements in the cards. At the beginning of each trial, an auditory cue indicated whether to switch or repeat the rule used on the previous trial. One second after each response, information about the correctness of the rule selection was provided by means of a positive or a negative visual feedback. (B) Mean reaction times (±SEM) from completed WCST series (solid squares) for the control group (black line) and the offender group (gray line). (C) Mean proportion of error through serial positions in the series (second, third, and last trials) for the control group (black columns) and the offender group (gray columns). $^{*}p<.05$.

the correctness of the given response. Crucially to the present study, as the cues and feedback signals are separately presented, the task permits us to observe and evaluate the ERP components emerging after each type of processing.

On one hand, an ERP component has been largely related to set-switching adjustments, the frontoparietal P3-like component (Stuss and Picton, 1978; Furumoto, 1991; Barceló et al., 2002; Periáñez et al., 2004; Watson et al., 2006; Cunillera et al., 2012). This ERP comprises of an increased positivity that peaks at approximately 300–500 ms after the cue signaling to *switch* to another rule, and was not observed after cues signaling subjects to *repeat* the same sorting rule. The switch-related P3 component has been interpreted as the neural signature of a cognitive control mechanism requested for task-set reconfiguration during task switching (Rushworth et al., 2002; Brass et al., 2005; Kieffaber and Hetrick, 2005; Nicholson et al., 2005; Slagter et al., 2005; Kopp et al., 2006; Swainson et al., 2006; Lai and Mangels, 2007).

On the other hand, a similar P3 component appears, but in that case, after the presentation of the first positive feedback in the trial series (Cunillera et al., 2012). Interestingly, this robust P3 component, with a frontoparietal distribution, emerges 300–500 ms after the presentation of the first positive feedback in a trial series, an event that occurs when these feedbacks appear after the correct set-switching trials. This P3 component has the largest amplitude in first-consecutive feedback, and dramatically decreases in consecutive positive feedback events in a trial series (Cunillera et al., 2012), indicating that this might be related to attentional resources devoted to the online monitoring of task demands. This interpretation is consistent with the context updating model of the P3 component (Donchin et al., 1986; Donchin and Coles, 1988), which states that the P3 component indexes a reconfiguration of attention to meet changing task demands and the requirement of a revision of the actual representation of the environment.

Finally, when regarding feedback or outcome-based adjustments in the WCST, the feedback-related negativity (FRN) has been identified as a neural signature related to the processing of negative feedback (Cunillera et al., 2012; Luft, 2014). The medial-frontal ERP component (FRN) peaking between 200 and 400 ms after the feedback presentation, indicates that an outcome is worse than expected (Gehring and Willoughby, 2004; Holroyd and Coles, 2002; Müller et al., 2005).

In the present study, we aimed to evaluate, for the first time, ERP components associated to the WCST in a sample of juvenile offenders. The novelty of the current investigation is that our WCST (Cunillera et al., 2012) allows us to dissociate between cognitive signals related to internal (set-switching) and external (feedback-processing) monitoring, involved in flexible environmental adaptation in that sample.

In legal terms, the word juvenile offender (with age range of 15–20 years old) refers to an individual who violates or transgresses the law and is often linked to violent behavior. This period between 15 and 20 years is critical for the development of cognitive control processes primarily because relevant prefrontal cerebral structures attain their neural maturation during this time period (Diamond, 2002; Segalowitz and Dywan, 2009). To clearly understand the neurobiological substrates of aggressive behaviors, it is important to consider separate individuals who exhibit the core-affective features of psychopathy from other types of violent non-psychopathic offenders (Patrick, 2008). Thus, our sample consisted specifically of *non-psychopathic violent juvenile offenders*.

Based on the presented results, there are some consistent findings in non-psychopathic offenders in relation to deficits in performing the WCST (Syngelaki et al., 2009; Dolan, 2012; Tuominen et al., 2014; but see Gorenstein, 1982; Appelof, 1985). Based on the results available up until now, we expected to find impaired performance on the WCST in the juvenile-violent offender group compared to the control group, reflected by a larger percentage of error trials and/or with more errors related to the switch trial. Regarding the ERPs, the focus is placed on different components related to cue and feedback processing. Even though no previous evidence is available to suggest which component could be more affected in the offender group, since deficits in the WCST are related to set-switching abilities (rule-switching or cognitive flexibility), a reduction in the amplitude of the cue-P3 component would be expected. On the other hand, if deficits are related to the ability to process the outcome (feedback-processing), a reduction of the FRN or the first-positive feedback-P3 component would be expected.

2. Results

2.1. Psychometric results

A Battery of psychometric tests was completed for all participants; Table 1 shows the results for both groups. Offenders showed larger Impulsiveness scores than control participants, but demonstrated no higher Risk Taking values. As expected, the mean scores on the Aggression Questionnaire were significantly higher for offenders in all dimensions. Offenders also scored significantly higher in the Sensibility to reward tests compared to the controls, but no group differences were found in the Sensibility to punishment test. Offenders scored significantly lower on all the facets of the Conscientiousness scale of the NEO-PI-R when compared to controls except for when it came to the analysis of Orderliness. Finally, differences were also observed in the Conscientiousness and Emotional Stability measured using the FFPI, with offenders scoring significantly lower on these two scales.

2.2. Behavioral data

Overall, the offender group ($M=65.67\%$, $SD=11.08$) and the control group ($M=73.50\%$, $SD=11.59$) showed non-significant differences in global accuracy in the WCST [$t(26)=1.83$, $p=.079$]. In a similar vein, no differences were found between groups regarding the number of set-maintenance errors (controls: $M=7.07$, $SD=3.91$; offenders: $M=8.43$, $SD=4.09$; $t(26)=-.90$, $p=.378$) highlighting the preserved performance of offenders in set-maintenance. To study the RTs from valid series, we subjected the trial type (switch, 1st, 2nd, and last rep.) and group to a repeated measures ANOVA (rmANOVA) test. The significant main effect of trial type [$F(3,78)=22.10$, $p<.001$] confirmed RT differences between successive responses over and during the series. The pair-wise ANOVA (Helmert contrast) between switch and consecutive trials confirmed the effect of switching [$F(1,26)=24.89$, $p<.001$]. Furthermore, so as to discover the effect of repetitions in the RT, we subjected the successive repetitions (1st, 2nd, and last rep.) and group to a new rmANOVA. No significant differences were found between conditions [$F(2,52)=2.33$, $p=.112$]. Interestingly, an overall slower RT for the offender group compared to the control group was found in the rmANOVA with all trial types (switch, 1st, 2nd, and last rep.) [main effect of group: $F(1,26)=8.96$, $p=.006$; interaction, trial type $\times$ group: $F(3,78)=.32$, $p=.626$]; and in the rmANOVA for all repetitions (1st, 2nd, and last repetitions) [main effect of group: $F(1,26)=11.21$, $p=.002$; interaction, trial type $\times$ group: $F(2,52)=2.62$, $p=.087$] (see Fig. 1B).

When analyzing the distribution of errors committed during the sequence, the results of the rmANOVA revealed that the errors where distributed differently in each trial type (1st rep., 2nd repetition, and last repetition of the rule) [$F(3,78)=88.06$, $p<.001$], and the significant linear trend [$F(1,26)=140.28$, $p<.001$] corroborated the progressive reduction of the proportion of errors in consecutive trials.

In general, and despite no general differences being found regarding the accuracy between groups, when we specifically analyzed the distribution of errors inside the sequences (1st rep., 2nd repetition, and last repetition of the rule), the offender group had a larger proportion of errors than the control group [$F(1,26)=8.24$, $p=.008$]. Importantly, the significant interaction between

Table 1 – Psychometric mean scores and *t*-test comparison between groups (controls vs. offenders).

	Controls		Offenders	
	M	SD	M	SD
Age	18.43	1.02	18.43	1.16
IQ	111.86	13.65	112.50	7.61
Impulsiveness	5.64*	3.84	13.00*	5.35
Risk Taking	9.21	3.75	9.57	4.01
Aggression total – AQ	62.79*	9.45	94.29*	15.83
Physical aggression	17,29*	2.81	32.29*	7.33
Verbal aggression	12.43*	2.24	15.50*	3.18
Anger AQ	16.43*	2.77	24.36*	4.75
Hostility AQ	16.64*	4.68	22.14*	4.77
CFQ TOTAL	33.46	9.73	38.29	6.22
Sensibility punishment	9.43	5.30	11.36	3.88
Sensibility reward	11.86*	4.07	15.36*	3.34
Conscientiousness – NEO-PIR	159.86*	16.89	130.29*	22.30
Self-efficacy	27.86*	4.55	21.00*	4.66
Orderliness	24.50	4.18	24.36	3.20
Dutifulness	29.57*	5.37	23.71*	5.21
Achievement striving	26.79*	3.53	22.36*	5.02
Self-discipline	25.43*	4.11	21.86*	4.16
Cautiousness	25.71*	5.38	17.00*	6.77
Conscientiousness – FFPI	68.21*	7.37	58.71*	9.84
Emotional stability – FFPI	72.64*	8.31	57.14*	13.35

* Significant at $p<.05$.

condition and group [$F(3,78)=3.39$, $p=.047$], and the post pairwise t-test comparisons contrasting the proportion of errors in each position type between groups, revealed that the offender group had a larger proportion of errors than controls in the 2nd rep. (see Fig. 1C): 1st repetition [$t(26)=.51$, $p=.618$], 2nd repetition [$t(26)=-3.10$, $p=.005$], and last repetition [$t(26)=-1.91$, $p=.068$]. This pattern of results confirmed that the offender group failed more often in discovering the new sorting rule, which in turn demonstrates the possible existence of switching problems.

2.3. *ERPs results*

2.3.1. *Cues-related to set-switching.*

A clear P3 component appeared with the presentation of the switch cue, peaking at ~375 ms after cue onset (see Fig. 2), in which a clear increase in the amplitude is observed in the control, compared to the offender group. This P3 component was nearly absent in consecutive repetition trial cues. This effect was confirmed by the significant main effect of trial type [switch, 1st, 2nd and last rep.: $F(3,78)=36.75$, $p<.001$], and by the pair-wise comparison (Helmert contrast) between the switch trial vs. all the other cues [$F(1,26)=49.89$, $p<.001$]. Despite a non-significant main effect of group being found [$F(1,26)=2.97$, $p=.097$], a significant interaction between group and trial type was obtained [$F(3,78)=3.27$, $p<.05$]. Importantly, further pair-wise group t-test comparisons of the mean P3 amplitude at central electrodes (Fz, Cz, and Pz), confirmed that the group differences were only significant in the switch-cue condition [Switch: $t(26)=2.33$, $p=.028$; 1st Rep.: $t(26)=-.43$, $p=.673$; 2nd Rep.: $t(26)=.73$, $p=.474$; Last Rep.: $t(26)=1.65$, $p=.110$]. This effect encountered in the switch condition was clearly evident at frontal and central electrode locations [Fz: $t(26)=2.58$, $p=.016$; Cz: $t(26)=2.05$, $p=.050$; Pz: $t(26)=2.07$, $p=.048$].

A new rmANOVA analysis was carried out to investigate the differences between the consecutive repetitions (1st, 2nd, and last Rep.). The significant main effect of trial type [$F(2,52)=11.78$, $p<.001$] confirmed the differences between these conditions. Regarding the group differences, no significant main effect or interaction on the group was encountered [$F(1,26)=.60$, $p=.445$; Type × Group: $F(3,78)=2.20$, $p=.122$].

2.3.2. *Feedback-processing.*

As can be observed in Fig. 3, both positive and negative 1st feedback elicited a large P3 peaking at ~330 ms after the feedback onset. This component appeared diminished in consecutive feedback. Furthermore, a negative peak appears around the 220 ms point in both 1st positive and negative feedback, resembling the well-know FRN component. As we expected, for positive trials, the P3 decreased as a function of feedback repetition.

Firstly, to analyze the FRN component we carried out a rmANOVA, contrasting the difference in waveform between the negative and the 1st positive feedback at frontal midline electrodes (Fz, FCz, Cz). The significant main effect of group [$F(1,26)=4.61$, $p<.05$] indicated a larger FRN for the offender group compared to the control group at all midline electrodes [electrode × group: $F(1,52)=2.14$, $p=.144$].

After that, we carried out a rmANOVA, contrasting all positive feedback at midline electrodes (Fz, Cz, Pz). The highest P3 for the 1st feedback stimuli and the progressive

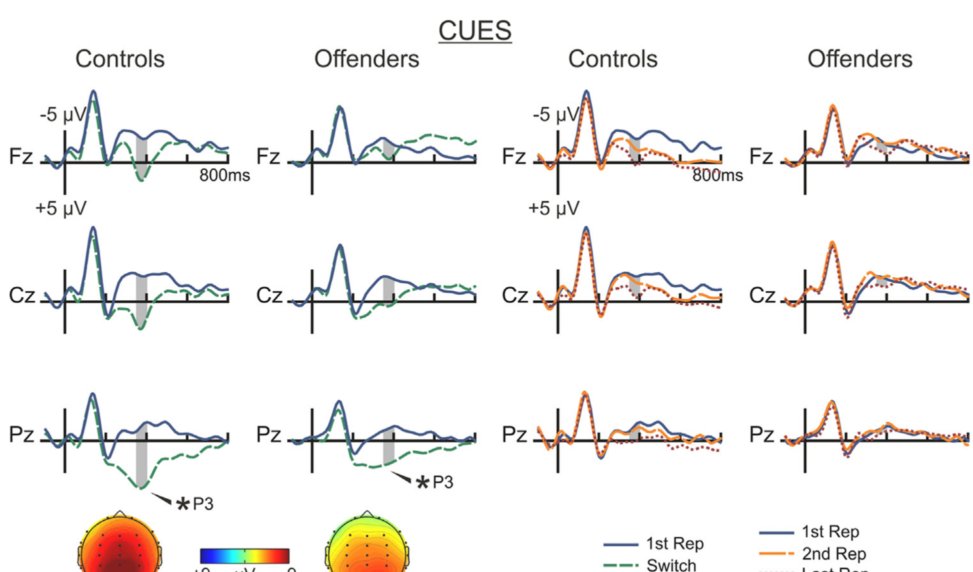

Fig. 2 – Cues-related ERPs. On the left side is shown the grand average of cue-locked ERPs for switch and 1st repetition, and for repeated cues (right side) at midline electrode locations (Fz, Cz, and Pz), for both the control and the offender group. A large P3 component is elicited by the switch cue that indicates that the participant should change the current classification rule. The scalp distribution for switch vs. 1st Rep. subtraction (bottom) corresponding to the time window 350–400 ms, for the control and offender groups is illustrated. On the right side are shown the grand average of cue-locked ERPs for repeated cues at midline electrode locations (Fz, Cz, and Pz), for both the control group and the offender group (right). Very similar ERP waveforms are observed for the consecutive repeat cues (1st Rep., 2nd Rep., and last Rep.); note the absence of the P3 component for repeat trials. For illustration purposes, the averages were low-pass filtered (low-pass filter, 12 Hz). Regions in gray indicate the time-window entered in the rmANOVA. The significant component was signaled by a *$p<.05$.

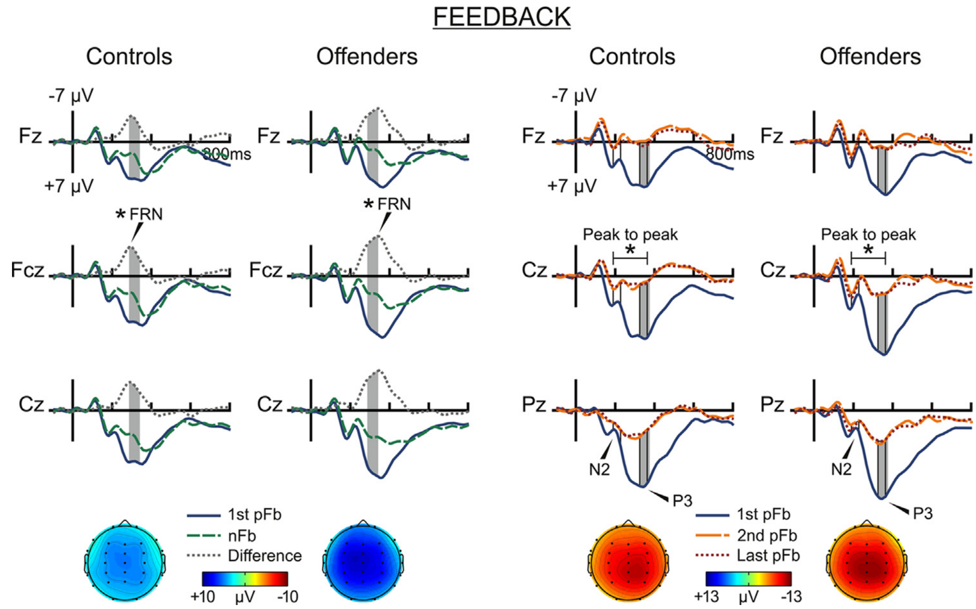

Fig. 3 – Feedback-related ERPs. On the left side is presented the grand average of feedback-locked ERPs for the 1st positive feedback and for negative feedback at the midline electrode array (Fz, Fcz, and Cz) for the control and the offender groups. A clear feedback related negativity (FRN) with a mid-central distribution (see isovoltage map below) is observed at the 290–340-ms time range when subtracting positive from negative feedback events. On the right side we see represented the grand average of ERPs for 1st, 2nd and last positive feedback, in which the electrophysiological responses at the midline electrode array (Fz, Cz, and Pz) for the control and the offender groups is illustrated. A clear P3-like component with a centro-parietal distribution is observed at the 320–370 ms time range, for the first positive feedback in the topographical map. For illustration purposes, the averages were low-pass filtered (low-pass filter, 12 Hz). Regions in gray indicate the time-window entered in the rmANOVA. Both small time-windows through the N2 and the P3 peaks which were used in the peak-to-peak analysis, were separated with thin black lines. The significant components were signaled by a *$p<.05$.

P3 amplitude reduction for consecutive feedback were corroborated by the significant main effect of trial type [1st positive, 2nd positive and last positive feedback: $F(3,78)=114.92$, $p<.001$] as well as by the pair-wise comparison with the Helmert contrast [$F(1,26)=159.49$, $p<.001$]. Furthermore, no significant differences were found between groups [$F(1,26)=1.55$, $p=.224$] (see Fig. 3). As the visual inspection suggested a larger P3 for the offender group compared to the control group, an additional peak-to-peak analysis was carried out in order to isolate these effects. A rmANOVA was conducted comparing groups with peak-to-peak amplitude measurements between the N2 and the P3 peaks at midline electrodes. The significant main effect of group [$F(1,26)=4.95$, $p=.035$] confirmed a larger P3 for the offender group compared to the controls.

3. Discussion

In the present ERP study we investigated set-switching (cue-related) and feedback processing (outcome-related) in a sample of non-psychopathic violent juvenile offenders, both cognitive control mechanisms are crucially involved in adapting our behavior to the demands of the environment. A modified WCST paradigm was used to assess both processes (Cunillera et al., 2012). The most important contribution of the present study is the finding that the performance problems traditionally observed in offenders in the WCST can be associated to set-switching problems and to alterations in the ability to evaluate information from external feedback. These results were observed in both the behavioral and the electrophysiological levels in the offender group, as indicated by (i) more proportion of errors when the new rule was implemented, (ii) a reduced amplitude in the P3-related to switching, and (iii) an increased FRN and P3, related to feedback processing. In the following paragraphs these results will be discussed in more detail.

Firstly, it is important to mention that the personality assessment revealed greater impulsivity and aggression scores confirming a clear impulsive/violent pattern in the offender group, together with higher scores in sensibility to reward. At the behavioral level, the offender group was slower than control participants, although both groups showed similar accuracy during the task. Importantly, overall slower reaction times were previously observed in offender populations when compared to healthy control groups (see Munro et al., 2007; Brazil et al., 2009, 2012; Vilà-Balló et al., 2014). Although a clear explanation for this decrease is not easy to offer, we could speculate that this effect could have arisen due to a general increase in the difficulty of the task for this group, requiring more cognitive or attentional resources. Notice that the overall accuracy of both groups overall was very similar, which means that the increased reaction time could be associated to a possible problem in the speed/

accuracy trade-off: slower reaction time is needed for obtaining a similar performance in the offender group.

Interestingly, similar results were obtained recently by Brazil et al. (2012), exposing a problem in speed-accuracy trade-off in adult offenders. In this cited study, a clear reduction of reaction time (nearly of 75 m s.) was encountered in the offender group (for both psychopathic and non-psychopathic participants) while no differences in accuracy were observed. Similar observations pointing to an impaired performance in offenders have been previously published (Morgan and Lilienfeld, 2000; Pham et al., 2003). It is also worth noticing that although accuracy was similar, the offender group committed more errors before changing the rule, especially after the 2nd repetition (see Fig. 1), suggesting that offenders might have deficits in set-switching, needing more time or information in order to become capable of changing the rule and to incur less failures through the implementation of new rules.

In sum, the present results regarding performance could be related to offenders having general difficulties in coping with these experimental situations, affecting their speed-accuracy trade off and probably also affecting the amount of effort or resources needed to implement cognitive control mechanisms and avoiding impulsive responses (Munro et al., 2007; Vilà-Balló et al., 2014; Tuominen et al., 2014). These findings of altered WCST performance are also at odds with what has been previously reported in traditional studies with non-psychopathic offenders using the WCST (Gorenstein, 1982; Appellof, 1985). These studies failed to find WCST performance deficits in offenders. On the other hand, the current pattern of findings supports the results obtained in more recent studies (Syngelaki et al., 2009; Tuominen et al., 2014), pointing to a specific switching deficit which may explain the difficulties in implementing new rules in this population.

When corroborating this pattern of results, cue-locked ERPs showed that violent juvenile offenders had compromised their rule-switching ability, which was indicated by a diminution of the cue-locked P3 amplitude for the switch, compared to the control group (see Fig. 2). In other words, the cognitive flexibility was clearly affected in our sample of offenders. Importantly, violent juvenile offenders had compromised only the set-switching process but not the set-maintenance process. Likewise, similar amplitudes were observed during the consecutive trials after correct switching (Cunillera et al., 2012), confirming that it was not a problem related to working memory. Thus, the finding of altered switch-P3 with a larger number of errors in implementing the new rule (despite no differences being evident in the total percentage of errors), is in accordance with the most recent findings which reveal that the nature of errors of offenders in WCST could be manifested in perseverative errors, rather than other type of errors (Syngelaki et al., 2009; but see Tuominen et al., 2014). Similar perseverative behavior was previously reported in children with conduct disorder (Van Goozen et al., 2004).

Furthermore, identifying deficits in cognitive flexibility in violent juvenile offenders is an important finding that may help to interpret their persistence in offending behavior. In the same vein, other studies have found a deficit in cognitive set-switching for this population, although this has been explained in terms of attentional deficits (Bergvall et al., 2001) rather than a deficit in cognitive flexibility.

Interestingly, the analysis of the feedback-locked ERP showed an altered pattern of feedback processing for the offender group compared to the control group. This result was evidenced by the increased FRN and P3-related to positive feedback for the offender group compared to the control group. The amplitude of the FRN is normally larger when the feedback or outcome is worse than expected (Holroyd and Coles, 2002; Luft, 2014). Thus, the present findings suggest that the offender group had difficulties in correctly predicting the negative consequences of their decisions, on the basis of previous external feedback. In addition, as the offender group showed a larger P3-related to positive feedback processing, it could be that their predictions were biased toward higher expectations on receiving positive feedback. These electrophysiological results are in line with the obtained psychometric measurements, which showed larger sensibility to reward in offenders. Similar alteration in reward processing was previously observed at the behavioral level by Syngelaki et al. (2009). In this study offenders showed a trend to increase risk-taking decisions related to reward-seeking behaviors. This reward-sensibility trend could be an additional element that needs to be considered together with their identified difficulties in cognitive flexibility.

Curiously, the alteration on feedback processing (related to the increased sensibility to reward) for offenders was restricted to the first feedback in the trial series. This is an important finding and may indicate that after updating the rule and after the first positive feedback is presented, offenders were able to release attentional resources devoted to the ongoing monitoring of task demands. In other words, despite the fact that the offender group failed to implement new rules due to difficulties in set-switching, when they found the correct rule, they could maintain it across trials without interference based on the correct monitoring and updating of information provided by the feedback signal. This interpretation of the feedback-related P3 in our tasks is based on the context updating model of the P3 (Donchin et al., 1986; Donchin and Coles, 1988; Cunillera et al., 2012). Accordingly, the P3 component may reflect a reconfiguration of subjects' attention to meet changing task demands.

In conclusion, the present study contributes to provide evidence for deficits in cognitive flexibility, reward processing, and in implementing new rules in non-psychopathic juvenile offenders. Despite it not being the first electrophysiological investigation studying executive abilities in offenders (see Hall et al., 2007; Bernat et al., 2007; Brazil et al., 2009; Vilà-Balló et al., 2014); the current study is the first one to provide evidence of ERP related to deficits in implementing new rules in non-psychopathic violent juvenile offenders, and shows that such deficits could be related to cognitive flexibility and feedback processing. Difficulties in cognitive flexibility were witnessed as a reduced cue-P3 in switch trials, and alterations in feedback processing as an increased FRN and P3-related to feedback, together with higher scores in subjects sensibility to reward. Behaviorally, these deficits were manifested in an increased proportion of failures after the switch trial, when participants were attempting to implement the new, correct rule. These alterations may account for the typical, inappropriate behavior observed in violent offenders, and most importantly, may provide clues for understanding the factors involved in the maintenance of their offending behavior. Worthy of notice is the fact that offenders have preserved their ability to maintain a sorted rule in working memory, as well as retaining their capacity to correctly monitor the current task. Intriguingly, the current finding is in line with previous neuroscientific research, suggesting that some different cognitive impairments (i.e. difficulties in flexibly switching between rules) were found in criminal violent offenders (Raine et al., 1994, 1998, 2000; Raine, 2002). Future investigations should be conducted to assess the temporal stability of these characteristics and the importance of these alterations as a risk factor in criminal behavior. Additionally, future studies are necessary to evaluate potential new preventive or rehabilitation programs based on the assumption that problems in implementing new behavior in violent offenders could be related to cognitive flexibility and reward processing.

4. Experimental procedures

All procedures were approved by the local ethics committee of the University. A written consent was obtained for all adult participants, and for minor legal tutors. In the case of minors, a full written consent was obtained.

4.1. *Participants*

Juvenile male offenders ($N=14$; mean age of 18.43; $SD=1.16$; mean IQ of 112.50; $SD=7.61$) were recruited for this study from the Juvenile Justice and Educative Center of Girona, youth detention center. The juvenile offenders, who were serving time for violent crimes; all of them having been incarcerated by the jurisdiction of a Spanish juvenile court under the current juvenile laws for extremely offensive violent behavior, were all inmates at the center. The average custodial sentence length of our participants was 19.63 months ($SD=10.42$). Summing the total number of convictions for all participants, the offender group had accumulated the following number of convictions: 31 for thefts (71%), 25 robberies (86% of offenders had committed a robbery), 18 for injuries (57%), 16 larcenies (50%), 9 threats (43%), 9 motor vehicle thefts (36%), 6 resistance/disobedience of a person in authority (36%), 6 property damage (21%), 4 unauthorized possession of firearms (29%), 3 direct assaults against persons in authority or their agents (21%), 3 libels (21%), 3 disorderly conduct (21%), 2 coercion (14%), 2 vandalism (14%), 2 domestic abuse (14%), 1 violation of court order (7%), 1 unjust vexation (7%), 1 sexual assault (7%), and 1 homicide (7%). Additionally, all had been diagnosed with conduct disorder by the staff at the center.

On the other hand, similar sex-, age- and IQ-matched control participants ($N=14$; mean age of 18.43; $SD=1.02$; mean IQ of 111.86; $SD=13.65$) were recruited from the University of Girona. All participants included in both groups had a normal IQ, had no previous history of severe head injury and were free from drug abuse or any psychiatric medication. Each participant filled out a battery of personality psychometric tests. All participants were part of a larger study in which different executive functions were tested (see Vilà-Balló et al., 2014).

4.2. *Psychometric testing*

Participants filled out the Spanish version of the following questionnaires: (i) the I7 Questionnaire (Luengo et al., 1991; Eysenck et al., 1985), measuring impulsiveness and risk-taking; (ii) the Aggression Questionnaire (Andreu et al., 2002; Buss and Perry, 1992), which is a measure of aggressiveness (total AQ score) that includes the subscales: Physical Aggression (AQ-PA), Verbal Aggression (AQ-VA), Anger (AQ-A) and Hostility (AQ-H); (iii) the Cognitive Failures Questionnaire (CFQ; Garcia and Sanchez-Canovas, 1994; Broadbent et al., 1982), which measures the disposition towards committing cognitive slips and errors (e.g., failures of memory, action, and perception) in everyday life; (iv) the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (Torrubia et al., 2001), taken as an index of sensibility to punishment and sensibility to reward; (v) the Revised NEO Personality Inventory (NEO-PI-R; Cordero et al., 1999; McCrae, Costa 2004), which was used to evaluate Conscientiousness facets (e.g., self-efficacy, orderliness, dutifulness, achievement striving, self-discipline and cautiousness); (vi) the dimensions of Conscientiousness and Emotional Stability (Rodríguez-Fornells et al., 2001) of the Five Factor Personality Inventory (FFPI; Hendriks et al., 1999); and finally, (vii) the Raven's Progressive Matrices was used to assess IQ (Raven, 1989).

4.3. *Stimuli and procedure*

We used a modified version of the WCST (Fig. 1A, Cunillera et al., 2012) to assess the participants. The trials began with an auditory cue which signaled subjects to repeat the rule used in the previous trials (65 dB tone; 250 ms duration; 2000 Hz) or to switch to another new rule (500 Hz). After the cue (1000–1700 ms later), a visual target containing 1 of the 24 target cards appeared at the center of the display. Beyond the target, the typical four WCST key cards were displayed. The target and the cards remained on the screen until participants responded. Participants had to respond with the index fingers of both hands, using a four-button response pad, corresponding to the layout of the four key cards. A feedback stimulus (a happy or sad smiley icon) indicated if the response was correct or erroneous, appeared 1000 ms after the response with a duration of 1000 ms. The next cue appeared 300 ms after the feedback.

The task consisted of 360 trials grouped into 60 series. In order to avoid participants predicting the beginning of a new series, the length of the series was randomized from between 5 and 7 trials (20 series for each number of trials). All trials of the same sequence consisted of the same sorting principle (color, shape, or number). The same number of blocks for each sorting principle was distributed in a semi-random order; to avoid two blocks of the same principle being presented consecutively. In this way, participants could not predict the succession of rules across the task. Following the same line, the 24 target cards were repeatedly used across the task in a random order within the series. Each target card had a specific combination of the three rules (one color, one shape, and one number; e.g., three red circles). In each choice, three of the four key cards, share respectively, only one of the three specific attributes with the target card, for that reason, participants could select each of the rules in every trial. This meant that one of the four key cards never shared any attribute with the target card. At the beginning of the experiments, participants were not informed about the initial sorting rule.

Importantly, a sequence was considered correct when the participant found the task rule on the first or on the second trial in the sequence and if the tasks rule was not missed during the sequence. As the sorting principle rule changes after each sequence in a semi-random order, participants had to make a guess after the cue shift. The probability of finding the correct rule on the consecutive sequence was 50%. These first trials with errors were defined as guess errors when they involved a shift in the rule and when they were followed by correct matches on all remaining trials of that series. As well as this, only series with a correct shift after the switch cues or series with guess errors on the first trial were considered as valid series and were included in the analysis of reaction times (RTs) and ERPs. This was with the exception of trials containing a switch error, these trials being included in the analysis of behavioral accuracy and ERPs of negative feedback.

Beforehand, participants were informed in detail about the characteristics of the experimental session and the characteristics of the task. They were instructed that during the task, they had to find the correct rule (color, shape, or number) to classify the target card on the basis of these three rules, and to use the information provided by the feedback stimulus – which indicated the correctness of their responses – to maintain or to change the sorting rule. They were advised that auditory cues would be presented at the beginning of each trial, indicating the maintenance of the same sorting rule or the change of rule in the following trial. The experiment only began when the examiner had made sure that participants perfectly and fully understood the task. In order to minimize the number of errors occurring during the task, participants could use the first five series of the experiment to practice with before they began. After each group of 12 trials, a rest break was given. Importantly, in the sequences after the breaks, the three rules were available to participants. In those cases, the probability of discovering the correct rule in the first trials was 33%. As well as this, during the task, participants were encouraged to minimize blinking. The experiment finished after approximately 45 min. The reduced number of practice trials was chosen to maximize the signal-to-noise ratio of the electroencephalographic (EEG) data.

4.4. *Electrophysiological recording*

The EEG was recorded using SYNAMP Neuroscan amplifiers from 29 tin electrodes mounted in an elastic cap located at standard scalp positions (FP1/2, F3/4, C3/4, P3/4, O1/2, F7/8, T3/4, T5/6, FZ, CZ, PZ, FC3/4, FT7/8, CP3/4, TP7/8, FCZ, CPZ), these recordings then being referenced on-line to an electrode placed on the right ocular canthus. EEG data was re-referenced afterwards offline to the mean of the activity of the two mastoid processes. Vertical eye movements were monitored by an electrode placed below the right eye. Electrode impedances were kept below 5 kΩ. The EEG and electro-oculogram (EOG) were recorded continuously and digitized at a sampling rate of 250 Hz (bandpass from .01 to 70 Hz). Epochs that exceeded $\pm 100\,\mu V$ in electrooculogram (EOG) or EEG were removed offline for further analysis using the extreme value function of the EEGlab toolbox.

4.5. *Behavioral analyses*

RTs were measured separately for correct trials in valid series for switch trials and for each repetition trial in the sequence (trial type: switch vs. 1st Rep. vs. 2nd Rep. vs. Last Rep.). These RT values were submitted to repeated measures ANOVA (rmANOVA) with the trial type as the within-subject factor and group (controls vs. offenders) as the between-subject factor.

To measure behavioral accuracy, different analyzes were carried out. First, we analyzed using a *t*-test the global accuracy which is the percentage of correct trials during the overall task. Secondly, another *t*-test analysis was used to asses differences in set-maintenance errors – which are errors involving occasional failures to maintain the chosen correct rule – between groups. Finally, the proportion of errors in each trial position was calculated, dividing the number of errors in each test by the total number of errors throughout. In order to discover the temporal distribution of errors within the series, a rmANOVA on the proportion of errors was carried out with the main trial type as the within-subject factor comprised of three levels (1st, 2nd and last repetitions of the rule) in accordance to the position of errors in the series, and group (controls vs. offenders) as the between-subject.

Due to the fact that the probability of discovering the correct rule in the switch trial was 50%, these trials were not included in that analysis. Only the first (first repetition of the new rule), second (second repetition of the current rule) and last trials (last repetition of the current rule) after the switch trial were included. Here, failures on 1st and 2nd repetitions were considered as failures in implementing the new sorting rule, because participants failed to correctly change between the previous and the new sorting rule.

4.6. *Event-Related Potentials (ERPs) analyses*

The ERP analysis was performed separately for cue-locked and feedback-locked data. Cue-locked ERPs for correct artifact-free trials were averaged for 1024 ms epochs (from −100 to 924 ms). The analysis was conducted separately for the first switch trial (switch), the first repeat trial (1st Rep.), the second repeat trial (2nd Rep.), and the last trial of the series (Last Rep.). Feedback-locked ERPs were averaged for 1024 ms epochs (starting 100 ms prior to the feedback signal), and were separately obtained on correct trials for the different positions of the positive feedback in the series (1st pFb, 2nd pFb, and Last pFb). Furthermore, feedback-locked ERPs for error trials were obtained. Only the 1st and 2nd negative feedback signals were averaged (errors on the switch trial and on the following trial after the switch). Set-maintenance errors, i.e., errors made after acquiring the correct rule, were excluded from the analysis.

Following previous ERPs studies on WCST, most of the present analysis focused on the P3 component (Stuss and Picton, 1978; Furumoto, 1991; Barceló et al., 2002; Periáñez et al., 2004; Watson et al., 2006; Cunillera et al., 2012). In the present study, the analyses were carried out separately for cue and positive events. The time window for each P3 amplitude was defined on the basis of each peak latency, identified at Pz electrode in the grand average waveform. The mean amplitude of each P3 was determined within a ± 25 ms time window centered on these latencies (Cue time window: 350–400 ms; Positive/Negative feedback time window: 320–370 ms). For the negative feedback (nFb), FRN amplitude was measured by averaging EEG data within a 290–340 ms time window.

To test amplitude variations between controls and offenders on cue-locked ERPs, the amplitude of the P3 was summited to a rmANOVA with trial type (four levels: switch vs. 1st Rep. vs. 2nd Rep. vs. Last Rep.) and electrode (three levels: Fz, Cz, and Pz) as within-subject factors, and group (controls vs. offenders) as between subject factor. Regarding the feedback-locked ERPs, different analyses were carried out in order to better isolate the P3 and the FRN effects. To test the effects of the positive feedback-related P3, the ERP amplitude of the P3 elicited for each positive feedback was assessed statistically through an rmANOVA with positive feedback type (three levels: 1st pFb vs. 2nd pFb vs. last pFb), and electrode (three levels: Fz, Cz, and Pz) for the within-subject factor, group factor (controls vs. offenders) as well as the between subject factor.

In order to disentangle and separate the differences between groups for the P3, we performed a complementary peak-to-peak analysis. The differences in amplitude between the N2 (time-window 190–230 ms) and the P3 peaks (time-window 325–365 ms) at the midline electrodes, were submitted to a rmANOVA with electrode (three levels: Fz, Cz, and Pz) for the within-subject factor, group factor (controls vs. offenders) as well as the between subject factor. For the FRN-difference waveform, negative feedback (1st plus 2nd) minus the first positive feedback, was submitted to a rmANOVA with electrode (three levels: Fz, FCz, and Cz) for the within-subject factor, group factor (controls vs. offenders) as well as the between subject factor. When it was necessary, follow-up analysis was conducted to test any specific ERP effects between the switch and repeat conditions, as well as between feedbacks.

The Greenhouse–Geisser epsilon correction was used to correct for possible violations of the sphericity assumption (Jennings and Wood, 1976), for statistical analysis when was necessary, moreover the adjusted p-values after the correction are reported.

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