Title:

Efficient but less active monitoring system in individuals with high aggressive predispositions

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Abstract: Aggressive behaviors in pathological and healthy populations have been largely related to poor cognitive control functioning. However, few studies have investigated the influence of aggressive traits (i.e., aggressiveness) on cognitive control. In the current study, we investigated the effects of aggressiveness on cognitive control abilities and particularly, on performance monitoring. Thirty-two participants performed a Simon task while electroencephalography (EEG) and electromyography (EMG) were recorded. Participants were classified as having high and low levels of aggressiveness using the BPAQ questionnaire (Buss & Perry, 1992). EMG recordings were used to reveal three response types by uncovering small incorrect muscular activations in ~15% of correct trials (i.e., partial-errors) that must be distinguished from full-error and pure-correct responses. For these three response types, EEG recordings were used to extract fronto-central negativities indicative of performance monitoring, the error and correct (-related) negativities (ERN/Ne and CRN/Nc). Behavioral results indicated that the high aggressiveness group had a larger congruency effect compared to the low aggressiveness group, but there were no differences in accuracy. EEG results revealed a global reduction in performance-related negativity amplitudes in all the response types in the high aggressiveness group compared to the low aggressiveness group. Interestingly, the distinction between the ERN/Ne and the CRN/Nc components was preserved both in high and low aggressiveness groups. In sum, high aggressive traits do not affect the capacity to self-evaluate erroneous from correct actions but are associated with a

decrease in the importance given to one's own performance. The implication of these findings are discussed in relation to pathological aggressiveness.

Keywords: aggressiveness; cognitive control; EEG; ERN/Ne; CRN/Nc; performance monitoring

Introduction

Aggressiveness is defined as an individual's predispositions to respond aggressively, to experience negative emotions and to hold hostile thoughts (Buss & Perry, 1992). Previous studies in pathological and healthy individuals have demonstrated that aggressive tendencies are linked to poor executive capacities. In maladapted populations, for example, violent offenders, Hancock, Tapscott, & Hoaken (2010) showed that deficits in executive functioning predicted the frequency and severity of intentional acts in physical aggression. Even in a normal population, higher aggressive traits have been associated with low inhibitory control capacities (Pawliczek et al., 2013; Zajenkowski & Zajenkowska, 2015). Conversely, higher cognitive control abilities predicted less aggressive behaviors in response to provocation (Wilkowski, Robinson, & Troop-Gordon, 2010). These evidences indicate that executive functioning and in particular cognitive control, may be valuable research targets to gain a better understanding of aggressiveness.

Cognitive control is a set of executive functions that are orchestrated to adjust behaviors, according to internal goals and environmental constraints (Ridderinkhof, Forstmann, Wylie, Burle, & van den Wildenberg, 2011). Among cognitive control mechanisms, some of them are mobilized proactively and others reactively, according to when a risk of making an error is detected (Braver, Gray, & Burgess, 2007; Braver, 2012). Indeed, the risk of making an error must be monitored efficiently in order to involve the appropriate proactive or reactive adjustment mechanism (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001). Monitoring capacities are often investigated using electroencephalography (EEG) in participants performing choice reaction time tasks in which the stimulus-response congruency is manipulated, such as the Flanker or the Simon tasks. Falkenstein, Hohnsbein, Hoormann, & Blanke (1991) and Gehring, Goss, Coles, Meyer, & Donchin (1993) reported a negative fronto-central activity emerging at the time of the response and peaking around 100 ms after the response, but only when participants were making errors. This event-related potential (ERP) has been called the error (-related) negativity (ERN/Ne) and is predominantly considered to reflect the involvement of the error detection mechanisms (e.g., Hajcak, Moser, Yeung, & Simons, 2005; Maier, Scarpazza, Starita, Filogamo, & Làdavas, 2016). Indeed, when the situation emphasizes accuracy over speed (e.g., financial penalties for errors), it is important not to make errors and the ERN/Ne is increased, whereas the ERN/Ne is reduced in situations for which the errors are not meaningful because the instructions emphasize speed over accuracy (e.g., Gehring et al., 1993; Hajcak et al., 2005). Another ERP component linked to the performance monitoring system was also reported by Falkenstein, Hohnsbein, & Hoormann (1995) and Falkenstein et al. (1991). This parameter referred as the error positivity (Pe) is a later centro-parietal component that peaks between 200 and 400 ms after the response. It is only observable during trials for which participants consciously detected their errors (Nieuwenhuis et al., 2001); its magnitude varies according to the degree of error consciousness (Leuthold & Sommer, 1999). Therefore, whereas the ERN/Ne indicates automatic internal performance feedback, the Pe is considered to reflect the conscious detection and evaluation of errors (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000).

The error-specificity of the ERN/Ne has been challenged by the findings of Vidal, Hasbroucq, Grapperon, & Bonnet (2000) who observed an ERN/Ne-like in non-error trials thanks to the use of electromyography (EMG) and a methodology to increase the spatial resolution of EEG recordings. More specifically, the EMG was recorded to reveal partial-errors that are engaged erroneous actions that are successfully detected, inhibited and corrected (Eriksen, Coles, Morris, & O'hara, 1985; Hasbroucq, Possamaï, Bonnet, & Vidal, 1999). Furthermore, in their work, the low spatial resolution of EEG was improved using the Laplacian transform technique (Babiloni, Cincotti, Carducci, Rossini, & Babiloni, 2001; Burle et al., 2015). Vidal et al. (2000) reported the classical ERN/Ne in errors, but also described an ERN/Ne-like following both partial-errors and correct responses, which differed by their magnitudes. Indeed, the ERN/Ne-like observed in correct responses, also called the correct-related negativity (CRN/Nc), is largely smaller in amplitude than the ERN/Ne observed after a partial-error, which is in turn smaller than the ERN/Ne in full-error responses. Despite these differences in amplitude, the three ERPs have similar temporal dynamics, topographies and are generated by the same cerebral regions: the supplementary motor area and/or the dorsal anterior cingulate cortex (Bonini et al., 2014; Fu et al., 2019; Roger, Bénar, Vidal, Hasbroucq, & Burle, 2010). Therefore, these components are thought to reflect an identical process varying in degrees according to performance (Weinberg, Dieterich, & Riesel, 2015). Even though the debates remain around the question of the functional significance of these brain activities, the observed differences in magnitudes between full-error ERN/Ne, partial-error ERN/Ne and CRN/Nc negativities confirm the capacity of the brain to monitor behavioral motor performances. Additionally, the combined analysis of the performance-related negativities (i.e., ERN/Ne and CRN/Nc) enables the precise distinction between the ability to self-evaluate one's own performance from the strength of the monitoring processes that is mobilized during the task. On the one hand, a reduced ERN/Ne in error trials along with an increased CRN/Nc in correct trials indicates a loss in the ability to self-evaluate the ongoing performance with less differentiation between erroneous and correct actions. This is the case for example in schizophrenic patients, in de novo patients with Parkinson disease and in patients with frontal lesions (Mathalon et al., 2002; Turken & Swick, 2008; Willemssen, Müller, Schwarz, Falkenstein, & Beste, 2009). On the other hand, a reduced ERN/Ne combined to a reduced CRN/Nc indicates a global reduction of the importance given to the evaluation of the motor performance. Such a pattern suggests that the monitoring system is less activated throughout the task, but that the ability to self-evaluate an ongoing performance is preserved. Consequently, investigating the CRN/Nc component appears to be relevant since it enables to decide between several interpretations that could be drawn from the reduction in ERN/Ne. Using the same methodology as Vidal et al. (2000), the current study combined the analysis of the negativities of all response types to highlight the monitoring processes in high and low aggressive individuals.

Numerous factors differentially modulate the magnitude of the ERN/Ne and the Pe (for a review, see Overbeek, Nieuwenhuis, & Ridderinkhof, 2005). In particular, a reduction in ERN/Ne is often associated with psychiatric disorders such as borderline personality disorders (de Bruijn et al., 2006) and schizophrenia (Charles et al., 2017; Mathalon et al., 2002). These studies suggest that a reduced ERN/Ne is a marker of psychopathology (Olvet & Hajcak, 2008). However, reduced ERN/Ne are also observed in externalizing populations in a broader sense such as conduct disorders and substance dependences (Hall, Bernat, & Patrick, 2007; Pasion & Barbosa, 2019) and in juvenile offenders (Vilà-Balló, Hdez-Lafuente, Rostan, Cunillera, & Rodriguez-Fornells, 2014). Aggressive behaviors, a common factor between psychiatric populations, externalizing behaviors and offenders (e.g., Mancke, Herpertz, & Bertsch, 2015; Zhou et al., 2016), thus seem to be associated with a reduction in ERN/Ne. Fewer studies investigated the effect of aggressiveness on the Pe amplitudes. Moreover, their results are less consistent. Comparing offenders and controls, Brazil et al., (2009) showed reduced Pe amplitudes in the offenders whereas Vilà-Balló et al. (2014) did not find any difference between the two groups. This inconsistency might be explained by the presence of psychopathic traits in the population of the Brazil et al. (2009) study compared to Vilà-Balló et al. (2014). Indeed, Steele, Maurer, Bernat, Calhoun, & Kiehl (2016) found larger Pe amplitudes in offenders scoring high in psychopathic traits compared to those scoring low. Psychopathic traits rather than aggressiveness itself may affect Pe amplitudes in these aggressive populations.

In the current study, the main goal was to investigate the effect of aggressiveness on performance monitoring. Considering the inconsistency of the findings relative to the Pe component, we did not set a hypothesis of the effect of aggressiveness on its amplitude. However, based upon previous studies (e.g. Charles et al., 2017; Hall et al., 2007; Vilà-Balló et al., 2014), we expected that the reduction in ERN/Ne in full-errors would be revealed in individuals showing high aggressive traits compared to those with low aggressive traits. Moreover, because our participants were well-adapted non-clinical adults, we hypothesized that the monitoring system in our sample would remain as efficient in distinguishing between erroneous and correct actions unlike what it is found in pathological populations (Mathalon et al., 2002; Turken & Swick, 2008; Willemssen et al., 2009). However, if the reduction in the ERN/Ne in erroneous trials is confirmed, then we should observe a similar reduction in the other ERPs to preserve the distinction between each ERN/Ne in the three response types. Consequently, in addition of the reduction in the ERN/Ne in full-error trials, we should observe a reduction both in the ERN/Ne in partial-error trials, and in the CRN/Nc in pure-correct responses.

Material and methods

1. Participants

Thirty-two right-handed volunteers recruited at the University of Lille participated in the study (18 women, mean age = 22.40 years, range from 19 to 28). Handedness was assessed with the Edinburgh Handedness Inventory (Oldfield, 1971). Exclusion criteria included motor and/or sensory disorders and a current medical treatment. They all gave written informed consent for taking part in this study. The ethics committee of the University of Lille (2015-9-S35) approved the experiment.

2. Procedure and task

2.1 Experimental task

The participant sat in a closed room facing a computer screen. She/he performed a modified version of the Simon task (Simon, 1990). Visual stimuli were created in the shape of a circle and of a square. Each participant was invited to respond as quickly and accurately as possible as a function of the shape of the stimulus. For example, holding a response button in each hand, the participant was required to press with the right hand if the stimulus was a circle and with the left hand if it was a square. Shape-to-response mapping rules were counterbalanced across participants. Importantly, the shapes were displayed on the right or on the left part of the screen. Although this dimension of the stimuli was salient, it was irrelevant for the task. Hence, 50% of the trials were labeled as “congruent” since the expected response was ipsilateral to the position of the stimulus (*e.g.* when a circle requiring a left response was presented on the left side of the display). Inversely, 50% of the trials were labeled as “incongruent” since the expected response was contralateral to the position of the stimulus (*e.g.* when a circle requiring a left response was presented on the right side of the display).

Each trial begun with the presentation of a fixation cross at the center of the screen during 300 ms. The stimulus appeared and remained displayed until a response was given or after a 1000 ms time lapse. Then, a black screen was presented during 1000 ms before the start of the next trial.

The experiment begun with a training block of 20 trials. During this training, visual feedback appeared for 500 ms after each response providing information about the accuracy of the current trial ("*Bonne réponse*" for a correct response, "*Mauvaise réponse*" for an error, "*Essayez d'aller plus vite*" for responses longer than 1000 ms). Then, the participant performed 10 blocks of 129 trials. A pause of 15 seconds was implemented between each block. The experiment lasted about 30 min.

2.2 Aggressiveness indices

Participants responded to the BPAQ Aggression Questionnaire (Buss & Perry, 1992; french version: Pham, Ducro, & Saloppé, 2011) after the end of the Simon task to avoid potential influences of the questionnaire on behaviors.

The BPAQ reveals traits in aggression and contains four subscales. The subscales *Physical Aggression* and *Verbal Aggression*) evaluate the external forms of aggression (i.e., the tendency to act with the focus to hurt someone). The subscale *Anger* evaluates the affective aspect of aggression and is defined as the physiological arousal associated with the preparation for aggression. This subscale assesses the individual differences in the frequency of experiencing the urge to act and the behavioral reactivity towards angry feelings (Poland, Monks, & Tsermentseli, 2016). Finally, the subscale *Hostility* relates to a more cognitive aspect of aggression and is defined as the tendency to evaluate negatively other people, which is often accompanied by a desire to harm others (Poland et al., 2016). Internal consistency was adequate in our sample for the total BPAQ scores, $\alpha = .86$, 95% CI [.79, .93] as well as for the four subscores: *Anger*, $\alpha = .68$, 95% CI [.51, .85], *Hostility*, $\alpha = .76$, 95% CI [.63, .89], *Physical Aggression*, $\alpha = .86$, 95% CI [.80, .93] and *Verbal Aggression*, $\alpha = .55$, 95% CI [.30,

.79]. These internal consistency values correspond to those found by Pham et al. (2011) with Cronbach's α below .70 both for the *Anger* and for the *Verbal Aggression* subscales.

3. Data Acquisition and Preprocessing

All electrophysiological data were recorded simultaneously using Ag/AgCl electrodes with the BioSemi© system (BioSemi ActiveTwo electrodes, Amsterdam). EEG signals were collected with 64 electrodes (10-20 system positions) mounted on an elastic cap. The vertical electro-oculogram (EOG) was recorded by means of two external electrodes placed below and above the left eye. The horizontal EOG was recorded by means of two external electrodes placed on the temples. The EOGs measurements were recorded to control for eye movement artefacts. The left and the right electromyographic activities (EMG) were recorded by means of two pairs of electrodes placed on the surface of the skin above the thumb-*flexor pollicis brevis* of each hand. These EMG measurements were recorded to detect partial-errors and the onset of all the muscular activities. The sampling rate was set to 1024 Hz. Electrophysiological data were collected during the experimental blocks of the Simon task only.

4. Electrophysiological data pre-processing

All the electrophysiological data pre-processing steps were done using BrainVision Analyzer 2.1© software (Brain Products, Munich, Germany).

The EMG data were filtered with a 10 Hz high-pass filter. Onsets of EMG activities were manually marked after visual inspection as it remained more precise than automatic algorithms (Staude, Flachenecker, Daumer, & Wolf, 2001). Experimenters were not aware of the nature of the trial being inspected. Based on the manual markers, all trials were classified as (1) pure-correct trials (i.e., trials with only one muscular burst on the correct side), (2) full-error trials (i.e., trials with only one muscular burst on the incorrect side), and (3) partial-error trials (i.e., trials containing two EMG activations, one on the incorrect side preceding the correct response).

The raw EEG data were filtered with a 0.16 Hz high-pass filter only and were referenced offline to the left mastoid. The EOGs were used to perform the ocular corrections on the EEG signals following the statistical method by Gratton, Coles, & Donchin (1983). All other artifacts were manually rejected after visual inspection of individual traces. To improve the spatial and the temporal resolutions of the EEG signals, the Laplacian transform was applied to the monopolar data (Babiloni et al., 2001; Burle et al., 2015). To perform this operation, signals were interpolated with the spherical spline interpolation procedure using 3 as the degree of spline and 15 degrees, for the Legendre polynomial (Perrin, Bertrand, & Pernier, 1987; Perrin, Pernier, Bertrand, & Echallier, 1989). Then, the second derivatives in two dimensions of space were computed. Thus, electrical brain activities are expressed in $\mu V/cm^2$.

5. EEG data processing

Information related to EMG onsets was superimposed upon the EEG signals. EEG data were segmented with respect to the EMG onsets of pure-correct, full-error, and partial-error EMG bursts. EEG segments ranging from 500 ms before and 500 ms after EMG onsets were baseline corrected (100 ms pre-EMG window). Time courses were averaged as a function of the response type.

Previous studies showed that the ERN/Ne is maximal at the FCz electrode (e.g. Bates, Kiehl, Laurens, & Liddle, 2002; Ladouceur et al., 2018; Taylor, Visser, Fueggle, Bellgrove, & Fox, 2018; Weinberg et al., 2016). Therefore, the magnitudes of the central negativities were measured at the FCz electrode. A peak-to-peak method (i.e., baseline-free method, Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Meckler, Carbonnell, Ramdani, Hasbroucq, & Vidal, 2017; Olvet, Hatchwell, & Hajcak, 2010) was applied in the time window between 50 ms and 250 ms after EMG onsets. However, as a peak-to-peak method to measure Pe amplitudes would have been contaminated by the variability of the ERN/Ne amplitudes, the mean positivity in a window frame between 200 ms and 400 ms after EMG onsets was used as an index of Pe amplitudes.

6. Experimental groups and statistical analyses

The aim of this study was to evaluate the relation between cognitive control capacities and aggressiveness. In the present study, ERN/Ne amplitudes in all response types were used as an indicator of the performance monitoring capacities. Partial-error rates were used as an indicator of the efficiency in reactive control. Finally, the post-error slowing and the Gratton effects (Gratton, Coles, & Donchin, 1992; Rabbitt, 1966) were used as indicators of the efficiency in proactive control.

The BPAQ median score was used to categorize participants as possessing high/low aggressiveness trait personalities. In our sample, the BPAQ scores ranged from 44 to 101, with 67 as the median score. The median-split method categorized 15 participants as low aggressive (i.e. they scored strictly less than 67 in the BPAQ) and 14 participants as highly aggressive (i.e. they scored strictly more than 67 in the BPAQ). Three participants were excluded from ANOVA analyses because their BPAQ scores were equal to the median score.

ANOVAs were performed using the R *aov* function available in the *stats* package (R Core Team, 2018). The behavioral performances (i.e., reaction times – RTs, accuracy, reactive and proactive control indices) were submitted to a one-level ANOVA with Aggressiveness as between-group factor. Performance monitoring indices were submitted to a two-level ANOVA with Aggressiveness (2) as between-group factor and Response-Type (3) as within-group factor. Post hoc Scheffé were applied when required and the effect sizes were calculated as eta-squared and partial eta-squared (η^2 and η_p^2, respectively) using the R *etaSquared* function available in the *lsr* package (Navarro, 2015). The alpha level was set to .05 for all analyses.

Results

The following results present the findings obtained during the Simon task in the total sample of 32 participants. We then report the results obtained in the sub-groups after categorizing participants with high and low aggressiveness traits using the total BPAQ score.

Global analyses

1. Accuracy and reaction times

Among the exploitable EMG recordings, a total of 72.6 %, 23.2 % and 4.1 % of trials were classified as pure-correct, partial-error and full-error, respectively. As classically found, incongruent RTs (478 ms) were longer than congruent RTs (453 ms), $t(31) = -12.41$, $p < .001$, Cohen's $d = 2.19$. The RTs in full-error trials were shorter (416 ms) than the RTs measured when correct responses were observed (i.e., combined pure-correct and partial-error trials, 465 ms), $t(31) = 10.65$, $p < .001$, Cohen's $d = 1.88$. The post-error slowing was significant: RTs in correct trials following an error were longer (511 ms) than the RTs in correct trials following a correct response (463 ms), $t(31) = -6.96$, $p < .001$, Cohen's $d = 1.23$. The Gratton effect was significant: the congruency effect was smaller after incompatible trials (-17 ms) compared to the congruency effect observed after compatible trials (69 ms), $F(1,124) = 26.88$, $p < .001$, $\eta_p^2 = .18$. Overall, the classical effects of the Simon task were replicated.

2. Performance monitoring

The ANOVA revealed the classical main effect of Response Type on ERN/Ne amplitudes, $F(2,93) = 23.52$, $p < .001$, $\eta^2 = .34$. The post hoc Scheffé test confirmed that ERN/Ne was larger in full-error trials than both in partial-error trials ($p < .001$) and in pure-correct trials ($p < .001$). ERN/Ne amplitudes were smaller in pure-correct trials than in partial-error trials ($p < .001$).

Task performance, cognitive control as a function of aggressiveness

ANOVA revealed no main effects of Aggressiveness on error rates, on RTs in full-error trials and on RTs in correct trials $F(1,27) = 0.12$, $p = .737$, $\eta^2 < .01$, $F(1,27) = 0.55$, $p = .466$, $\eta^2 = .02$ and $F(1,27) = 0.34$, $p = .565$, $\eta^2 = .01$, respectively. These results are presented in Table 1. There was a main effect of Aggressiveness on the Simon effect, $F(1,27) = 7.35$, $p = .012$, $\eta^2 = .21$ (cf. Figure 1). The high aggressiveness group had a larger Simon effect (31.13 ms) than the low aggressiveness group (21.74 ms). When considering the partial-error rates reflecting reactive control, results revealed no main effects of Aggressiveness, $F(1,27) = 0.06$, $p = .816$, $\eta^2 < .01$. When considering proactive control, the ANOVA revealed no main effects of Aggressiveness on neither the post-error slowing nor the Gratton effect, $F(1,27) = 1.45$, $p = .239$, $\eta^2 = .05$ and $F(1,27) = 0.38$, $p = .545$, $\eta^2 = .01$, respectively.

Table 1.

Means and Standard Deviations for the Task Performance Indices in the High and the Low Aggressiveness Groups.

Note. Correct trials refer to both pure-correct and partial-error trials. Low and high aggressiveness groups were created based upon the median BPAQ score. M = mean, SD = standard deviation, RT = reaction time, η^2 = eta-squared.

	Low aggressiveness		High aggressiveness		F	p	η^2
Behavioral indices	M	SD	M	SD			
Full-error rates (%)	3.55	1.52	3.77	1.97	0.12	.737	< .01
Partial-error rates (%)	21.88	10.14	20.95	11.12	0.06	.816	< .01
RTs in full-error trials (ms)	382.51	44.32	369.69	49.11	0.55	.466	.02
RTs in correct trials (ms)	417.87	40.10	408.34	47.98	0.34	.565	.01

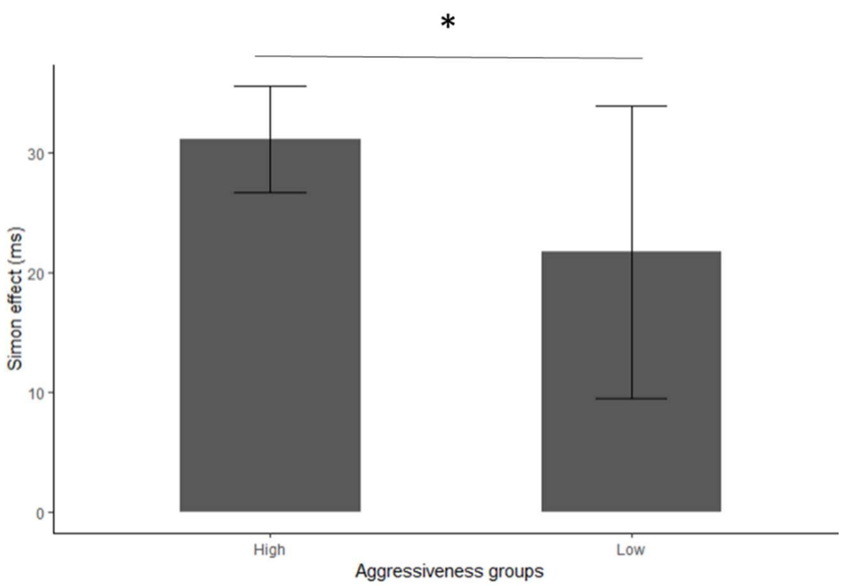

Figure 1. Mean Simon effect (ms) in the high and the low aggressiveness groups. Error bars represent standard deviations. *: $p < .05$.

Performance monitoring and aggressiveness

The EEG traces are represented in Figure 2 as a function of aggressiveness groups and responses types. The analyses revealed a main effect of Aggressiveness on ERN/Ne amplitudes, $F(1,81) = 10.53$, $p = .002$, $\eta_p^2 = .12$. The ERN/Ne amplitudes were smaller in the high aggressiveness group (-0.56 µV/cm²) than in the low aggressiveness group (-0.77 µV/cm²). Reductions in ERN/Ne amplitudes in the high aggressiveness group were not modulated by Response Type, $F(1,81) = 0.18$, $p = .833$, $\eta_p^2 < .01$. Concerning the Pe observed in full-error trials, there were no differences in amplitudes between the high and the low aggressiveness groups, $F(1, 27) = 1.00$, $p = .326$, $\eta_p^2 = .04$. Table 2 presents the ANOVA results for the performance-related negativities (i.e., both ERN/Ne and CRN/Nc) and the Pe amplitudes.

Table 2.

ANOVA Results for Mean Performance-Related Negativities and Pe Amplitudes.

	Performance-related negativities			Pe		
Factors	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Aggressiveness	**10.53**	**.002****	.12	1.00	.326	.04
Response Type	**23.21**	**<.001*****	.36			
Aggressiveness x Response Type	0.18	.832	< .01			

Note. Performance-related negativities refer to ERN/Ne in full-errors and in partial-errors responses and CRN/Nc in pure-correct responses. Bold text refers to significant effects. **: $p < .01$, ***: $p < .001$. η_p^2: partial eta-squared.

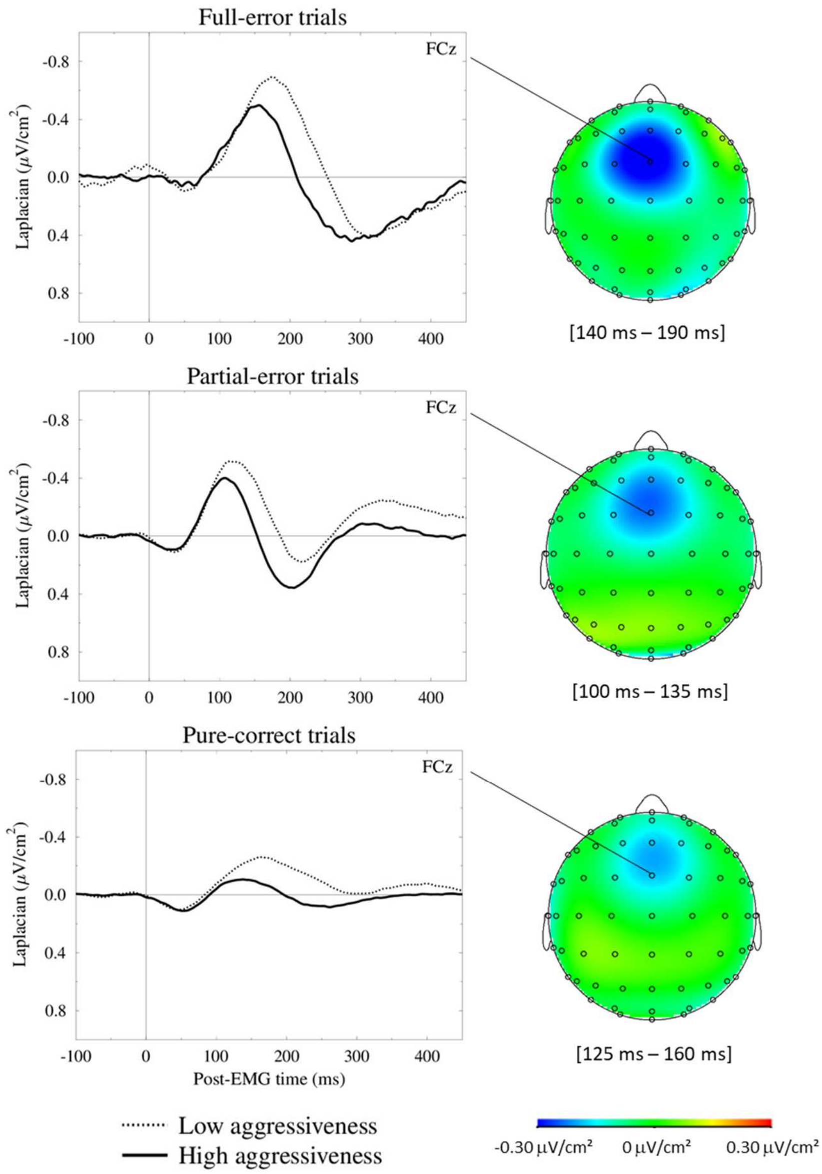

Figure 2. The Laplacian transformed performance-related negativities (both ERN/Ne and CRN/Nc) and Pe (FCz electrode) and the corresponding Laplacian topographies measured in the full-error (top panel), in the partial-error (middle panel) and in the pure-correct responses (bottom panel). Continuous lines and dotted lines represent the results obtained in the high and the low aggressiveness groups, respectively. Signals were locked to the EMG onset of the motor responses. The topographical maps (right column) show a top/horizontal view of the scalp (nose up) with the actual distribution of the Laplacian-transformed EEG data, separately for each response type, at the time of the negativity peak maximum.

Discussion

Aggressiveness is often associated with poor executive functioning and reduced performance monitoring in pathological and maladapted populations (e.g., Hancock et al., 2010; Vilà-Balló et al., 2014; Zajenkowski & Zajenkowska, 2015). The aim of the current study was to explore cognitive control capacities, and in particular performance monitoring, in a non-clinical population characterized with low and high aggressiveness personality traits. At the behavioral level, the findings showed that the high aggressiveness group globally performed as well as the low aggressiveness group in terms of accuracy and RTs. However, individuals with high aggressive traits were characterized by a greater congruency effect compared to those with low aggressive traits. At the brain level, the current study confirmed the expected reduction in ERN/Ne amplitudes in full-error trials in the high aggressiveness group compared to the low aggressiveness group. Interestingly, the results extended this finding by also revealing a reduction in performance-related negativities after both partial-errors and pure-correct responses. Additionally, the global reduction that was observed in all performance-related negativities amplitudes in the high aggressiveness group did not interact with the response types. Overall, the present results showed a reduction in the global activation of the performance monitoring system, and not a decrease in its efficiency.

Aggressiveness effects on cognitive control at behavioral level

Aggressive behaviors are known to be related to disturbed cognitive control abilities. Indeed, several studies investigating aggressiveness in tasks manipulating the stimulus-response congruency have reported worse performances in pathological and populations with problematic behaviors than in healthy controls (e.g., Gastaldo, Umiltà, Bianchin, & Prior, 2002; Hancock et al., 2010). In the current study, the performances of the participants in a choice RT task requiring cognitive control mechanisms were considered through the prism of their predispositions to act aggressively. We selected the BPAQ to assess the levels of aggressiveness through a 35-item questionnaire (Buss & Perry, 1992; Pham et al., 2011). A modified version of the Simon task manipulating the stimulus-response congruency was used to reveal cognitive control functioning. Results showed no differences in the global performance in the Simon task between groups of individuals categorized as having high and low traits in aggressiveness (i.e., RTs and error rates). Additionally, there were no differences neither in partial-error rates nor in behavioral adjustments indicating no effects of aggressive traits, both on reactive and proactive control mechanisms, respectively. However, the high aggressiveness group showed a larger congruency effect than the low aggressiveness group, revealing higher difficulty in inhibiting irrelevant information with higher aggressive tendencies. This result is consistent with a previous study showing longer reaction times in incongruent trials in schizophrenic patients compared to control participants (Gastaldo et al., 2002). While the few differences at the behavioral level between the two groups in our study may seem disconcerting at first sight, they might not be so surprising. Firstly, our participants were young individuals, recruited at the University, without maladapted behaviors. Secondly, the experimental setup was made to not induce aggressive behaviors, like it has been done in some previous studies (e.g., Krämer, Kopyciok, Richter, Rodriguez-Fornells, & Münte, 2011; Pawliczek et al., 2013). Therefore, the traits in aggressiveness were not amplified, and consequently the impact of such a trait may be too weak to be observable within the global indices of behavioral performances (i.e., RTs and error rates). Even if the global performances were not sensitive enough to the trait of aggressiveness in our study, the brain responses revealed a different pattern.

Aggressiveness effects on cognitive control at the brain level

Electroencephalographic recordings were used to assess performance monitoring abilities through the analysis of a specific response-locked ERP that is the error(-related) negativity (ERN/Ne) and its equivalent in pure-correct trials (CRN/Nc). These EEG components are fronto-central negativities peaking rapidly after the response. The amplitude of the ERN/Ne is known to vary as a function of the need to self-evaluate behavioral performances. The more the error is meaningful, the larger is the ERN/Ne amplitude (Gehring et al., 1993; Hajcak et al., 2005). In the current study, we choose to use the Laplacian transform to improve the temporal and spatial resolutions of the EEG (Babiloni et al., 2001; Burle et al., 2015) and especially to uncover the CRN/Nc, usually masked by a large parietal positivity (Roger et al., 2010; Vidal, Burle, Bonnet, Grapperon, & Hasbroucq, 2003; Vidal et al., 2000). We conducted a combined analysis of the negativities in full-errors, in partial-errors and in pure-correct trials. This joint analysis provides the means to specify how a variable can affect patterns of performance monitoring abilities (e.g. task instructions, disorders). In our opinion, only investigating the effect of a variable on the amplitude of the ERN/Ne can mislead interpretations. A reduced ERN/Ne cannot be a marker of error monitoring deficit if the CRN/Nc is also reduced: the monitoring system still distinguishes erroneous and correct actions. This pattern of results should be interpreted as a global decrease in monitoring engagement (i.e., reduction in the value placed on the performance). On the contrary, if a reduced ERN/Ne goes along with a large CRN/Nc, this pattern should be interpreted as a specific difficulty in the evaluation of one's own performance: the monitoring system becomes less discriminant.

In the current study, the performance-related negativities peaks were observed within a time window of 100 to 200 ms after the onset of the muscular responses recorded using EMG. Its amplitude was the highest in full-error, intermediate in partial-error and the smallest in pure-correct responses. This pattern of results replicated previously reported findings (e.g., Meckler et al., 2011; Roger et al., 2010; Roger, Castellar, Pourtois, & Fias, 2014; Vidal et al., 2003, 2000). Considering the aggressiveness effect, the ERN/Ne in full-errors was reported to be decreased in individuals showing high traits in aggressiveness compared to those with low aggressive traits. The current study replicated the findings by Vilà-Balló et al. (2014) in an adapted population and without manipulating the aggressive states of the participants. Interestingly, thanks to the Laplacian transform and the use of EMG, the current study extended these findings by revealing a reduction in the ERN/Ne in partial-errors and in CRN/Nc in pure-correct trials in the high aggressiveness group compared to the low aggressiveness group. Since all the negativities were affected in the same way by aggressiveness, the current findings suggest that aggressiveness does not affect the ability to self-evaluate actions, but instead reduces the importance attached to one's own performance. This global reduction in negativities amplitudes is consistent with several previous studies. Indeed, aggressiveness has already been linked to reduced prefrontal activities in an emotion-manipulated context (Pawliczek et al., 2013) and after exposure to violent video games (Hummer, Kronenberger, Wang, & Mathews, 2019). Nevertheless, the study showed that high aggressive predispositions are characterized by a less active, but still efficient monitoring system even in a neutral situation. It seems that high aggressive individuals care less about their performance than low aggressive individuals do, but are still able to clearly evaluate it. Further studies should consider the functioning of the monitoring system in high aggressive individuals in motivational situations to understand whether the global reduction observed here, in a neutral environment, is due to a genuine inability to mobilize the monitoring system.

Aggressive behaviors are characteristic of psychiatric populations (e.g., Mancke et al., 2015; Zhou et al., 2016) and these disorders are also associated with a reduction in the ERN/Ne amplitude (e.g., Charles et al., 2017; de Bruijn et al., 2006). Olvet & Hajcak (2008) even proposed that the ERN/Ne should be considered as an endophenotype of psychopathology. In the current study, we did not carry out precise psychiatric screenings for ethical reasons and, thus, it might be possible that in our sample, especially in the high aggressiveness group, some may meet criteria of psychiatric disorders. Moreover, aggressive predispositions are risk factors for psychiatric disorders (e.g., Mula et al., 2015). Considering the high aggressiveness group as at risk to develop psychiatric disorders, the current results suggest that the global reduction in performance monitoring activities reflects a neurophysiological marker for psychiatric vulnerability. However, this decrease in involvement of the monitoring resources itself is not sufficient to suggest the existence of a psychopathological state. In contrast, a difficulty in distinguishing between erroneous and correct actions may be a more accurate marker of maladapted behaviors. Accordingly to this hypothesis, Hall, Bernat, & Patrick (2007) and Mathalon et al. (2002) both showed weaker differences between ERN/Ne and CRN/Nc amplitudes in externalizing disorders and in schizophrenia, respectively, than in healthy individuals. The interpretation of the reduction in ERN/Ne as a marker of psychopathology (Olvet & Hajcak, 2008) should also take into account the modulation of the CRN/Nc to confirm the presence of disturbed self-evaluation capacities and to specify the true nature of abnormal cognitive control functioning of the monitoring system.

Conclusions

This study used the BPAQ questionnaire in order to evaluate aggressive tendencies in a non-clinical and adapted population to compare cognitive control capacities between individuals with low and high aggressive personality traits. At the behavioral level, the high aggressiveness group was associated with a larger congruency effect compared to the low aggressiveness group. However, this difficulty in inhibiting irrelevant information was not reflected in performance: the high and low aggressiveness groups differed neither on error rates nor on reaction times. More particularly, the aim of the current research was to study the influence of these personality traits on the performance monitoring system, which plays a crucial role in cognitive control. Individuals with high aggressive traits showed a reduction in performance-related negativities amplitudes independent of the response type compared to those in the low aggressiveness group. This reduction reveals a decrease in the value placed on performance, but an intact capacity to self-evaluate one's own performance in high aggressiveness. Further studies should be conducted in order to disentangle the influence of aggressive personality traits from the influence of a psychiatric diagnosis on performance monitoring capacities.

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