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Disruption of volitional control in obsessive-compulsive disorder: Evidence from the Bereitschaftspotential

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ABSTRACT

In the context of controversies involving possible abnormalities in the volition and action control in obsessive-compulsive disorder (OCD), the current study examined electroencephalographic correlates of automatic and volitional brain processes involved in the genesis of spontaneous movements in individuals diagnosed with OCD. For this, the amplitudes of early and late Bereitschaftspotential (early BP and late BP) from 12 patients and 12 controls were obtained while they performed spontaneous button presses under different levels of volitional experience. In the first condition, participants were distracted from their motor actions by a mental task (automatic condition) and in the second condition they were instructed to attending to their own intention to move (willed condition). The results corroborate previous report that the attention to (and, presumably, the awareness of) intention to act accounts for the expression of significant portion of the late BP in healthy individuals. More relevantly, the increased late BP in willed condition in relation to automatic condition was not present in the OCD group. Neither groups nor conditions affected the early BP. In sum, the current findings suggest the existence of abnormalities in the brain activities associated with the establishment of volitional control in OCD patients.

1. Introduction

The obsessive-compulsive disorder (OCD) is characterized by an impaired control of automatic impulses associated with the genesis of obsessions and compulsions, causing significant impact in the quality of life of affected individuals (Abramowitz et al., 2009). There is a growing body of evidence suggesting that the pathophysiology of OCD is associated with hyperactivation of cortico-basal ganglia circuits including the anterior cingulate cortex (ACC), orbitofrontal cortex (OFC) and caudate nucleus (Menzies et al., 2008), especially in symptoms' triggering situations (Breiter and Rauch, 1996; Adler et al., 2000). Current theories suggest that these circuits are involved in the acquisition and execution of automatic action patterns, i.e. streams of cognitive or motor activities mostly driven by contextual demands rather than by volition, especially when associated with motivational or affective factors (Graybiel, 1997, 1998). These evidences support the hypothesis that the OCD symptoms arise from an unbalanced interaction between hyperactivated automatic impulses and insufficient mechanisms of volitional restraints. This hypothesis constitutes the basis of the main pathophysiological models currently proposed for explaining the OCD (Nakao et al., 2014) although the role of volitional action control processes involved in the suppression of maladaptive impulses is still debated.

Psychophysical studies involving OCD patients have consistently shown deficiencies in overriding prepotent (or automatically selected) responses even if these responses are not specifically related to obsessions or compulsions (Bannon et al., 2002; Tolin et al., 2002; Chamberlain et al., 2006; Penadés et al., 2007). However, the role of this dysfunction in the pathogenesis of OCD remains controversial due to somewhat divergent theories. On one hand, a primary deficit in

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volitional action control could imply a disinhibition of certain automatic action pathways involved in the genesis of context driven impulses (Bannon et al., 2002; Penadés et al., 2007). On the other hand, the oversensitiveness of automatic action tendencies (Greenberg et al., 2000) could account for the relative impairment of normally operating volitional control. For clarifying this issue, it is essential to examine how neural correlates of volitional control are manifested in individuals with OCD.

Studies investigating neural activities associated with the process of overcoming prepotent responses during speeded choices have found conflictive results with evidences of both decreased (Nakao et al., 2005; Roth et al., 2007; Gu et al., 2008; Page et al., 2009) and enhanced (Ruchsow et al., 2007; Ciesielski et al., 2011; de Wit et al., 2012) activation surrounding brain regions involved in top-down action control. In addition to generic methodological factors that could account for this variability of results, such as statistical power or signal-to-noise ratio, it is important to acknowledge that neural activities involved in suppressing impulsive responses may spatially and temporally overlap with parallel processes, such as stimulus processing, target recognition, stimulus-response mapping and response monitoring, that may also be affected in OCD. In fact, OCD was previously associated with abnormal attention and stimuli processing (Okasha et al., 2000) as well as with an exacerbated response monitoring activity from medial frontal cortex (Gehring et al., 2000; Hajcak and Simons, 2002; Nieuwenhuis et al., 2005; Carrasco et al., 2013).

For approaching some of these conceptual and methodological issues, this study investigated the neurophysiological correlates of a very simple action control task consisting of the spontaneous flexion of a finger. By "spontaneous", we understand that the onset of the movement was predominantly determined by the participants themselves rather than by external events. There are evidences supporting that even the simplest voluntary movements are preceded by pre-conscious brain activities (Libet et al., 1993) manifested up to two seconds before the movement onset. These activities are associated with the detection of the Bereitschaftspotential, also known as readiness potential, an electroencephalographic negative slope widely distributed over the vertex (Kornhuber and Deecke, 1965). Taking into account estimated timing of the conscious intention to act (Libet et al., 1993; Haggard and Eimer, 1999), researchers admit that after several hundreds of milliseconds, these subliminal tendencies can assume a conscious representation, presumably enabling volitional mechanisms of action control (Libet, 1985).

Based on William James' pragmatic analysis of motor control experiences, voluntary actions can be classified into two categories. The first corresponds to the automatic (originally denominated ideo-motor) actions, which are generated "unhesitatingly and immediately the notion of it in the mind", without "a mental antecedent, in the shape of a fiat, decision, consent, volitional mandate, or other synonymous phenomenon of consciousness", "we think the act, and it is done; and that is all that introspection tells us of the matter" (James, 1890). This variety includes most of our daily actions, such as opening the door, turning the light on or turning the pages of a book, and results from previously established association between contextual demands and actions (Isoda and Hikosaka, 2011). On the other side, actions are considered willed (or volitional) when we consciously pay attention to their selection (Frith et al., 2016), that is, when they arise from deliberate choices of whether or how to act. Based on subjective experiences, it can be verified that in ordinary circumstances (excluding certain cases of disorders of volition), the explicit attention to intention to act can be considered a sufficient, and even necessary, condition for individuals becoming aware of their possibility of acting and, thus, experiencing the will to act (role of attention in conscious experience is discussed in Dehaene and Naccache, 2001).

To understand how determined action can be performed under different expression of will, let's consider the act of turning the light switch on. There is no objection that in ordinary circumstances, specially when we are distracted by random stuffs, this action tends to initiate automatically, without the clear expression a conscious fiat. However, when explicitly instructed to turn the switch "at will" in the following few seconds, we become aware about our possibility of moving (analogously, the possibility of not moving) and the action is now experienced as the result of a deliberate choice. Comparing analogue situations, in a previous study (Takashima et al., 2018), we supported the hypothesis that automatic and volitional processes of motor preparation contribute differently for the subcomponents of the readiness potential. The first processes account largely for the so called early Bereitschaftspotential (early BP), a subtle negative slope which characterizes the onset of the readiness potential. The second, for at least part of the late Bereitschaftspotential (late BP), a steeper negative slope during the last half second of the readiness potential (Shibasaki and Hallett, 2006).

Specifically, the objective of the current study was to examine event-related potential´s (ERP) correlates of automatic (unconscious) and volitional (conscious) processes of motor preparation in OCD patients. For this, we compared the amplitudes of early BP and late BP from OCD patients and controls while performing button presses under different levels of awareness. In the first condition, an incidental mental task was introduced for diverting participants' attention from their intention to act (automatic condition). In the second condition, participants were explicitly instructed to move their hands at will, i.e., when they wanted to move (willed condition). According to a previous study using similar experimental approach (Takashima et al., 2018), a reduced expression of the late BP in automatic condition compared with the willed condition was expected in the control group. If individuals with OCD present deficit associated with the establishment of volitional action control, the expectation was that a relatively damped late BP specifically in the willed condition could be identified.

2. Methodology

2.1. Participants

Twelve patients with diagnosis of OCD (DSM-IV: 300.3; APA, 1994) were recruited from the OCD outpatient clinic of the Psychiatric Hospital of the University of São Paulo. The exclusion criteria included history of neurological disease, drug addiction, psychotic symptoms and individuals whose main psychiatric disorder was not the OCD. The patients presented mean age of 41.17 ± 13.58 (mean ± standard deviation) years, nine were female and one left-handed (according to self-report). Only one participant was recently diagnosed and was not receiving treatment. All the remaining eleven patients were receiving serotonin selective reuptake inhibitors and presented refractory symptoms. Five patients had past history of other psychiatric disorders, including major depression, panic disorder and generalized anxiety disorder. One patient had current diagnosis of major depression. Patients' mean severity score on the Yale-Brown Obsessive Compulsive Scale (Y-BOCS) (Goodman et al., 1989) was 18.50 ± 5.18 (mean obsessions subscale score 8.67 ± 2.9; mean compulsions subscale score 9.83 ± 2.97).

Control subjects with no past or current symptoms of OCD were matched with the patients with respect to age and sex (9 female, mean age 41.17 ± 14.42 years, all right handed). None of the control participants presented history of neurological or psychiatric disorder. All participants, patients and controls, provided informed consent in written form. The experimental protocol was approved by the hospital's ethic committee.

2.2. Stimuli and procedures

The participants were seated in a dark and noiseless room facing a computer monitor (LCD, 22 inches, 60 Hz) located at a distance of about 60 cm. The button presses were recorded with the commercial

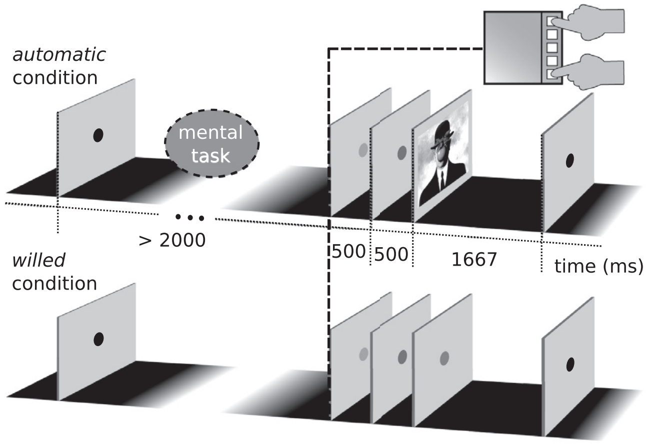

Fig. 1. Scheme of the task. Sequence of trial events in automatic and willed conditions.

Serial Response Box™ (Psychology Software Tools, PST Inc.). The visual stimuli were generated using the Psychtoolbox version 3 (Brainard, 1997). The EEG was recorded using a actiCHamp system (BrainVision®) with 64 electrodes. The experimental protocol was based on our previous study on the effect of conscious intention to act on the readiness potential (Takashima et al., 2018).

2.2.1. The automatic condition

The trial started with a black fixation point (radius 0.2°) in the centre of a grey screen. After a button was pressed, the fixation point changed colour to yellow (for 500 ms) and red (for another 500 ms) and, then, the centre of the screen was covered by a picture (70.4 cm^2 of area). Immediately after its presentation, the picture gradually disappeared (for 1667 ms) so that the black fixation point became visible again, as at the beginning of the trial. The sequence of visual stimuli in a trial is schemed in Fig. 1. The pictures consisted of 30 paintings of René Magritte, each one repeated in five consecutive trials, making up a total of 150 trials. After those trials in which each painting was presented for the last time, a screen with the text "next image" was displayed (for one to two seconds).

The participants were instructed to: 1-) keep their eyes on the fixation point; 2-) press the button with the index finger (left or right hand, according to the block); 3-) pay attention to the picture during its brief presentation; 4-) as the main task, while looking at the fixation point, make a creative thought based on the picture and express it "clearly" (no precise information of what "clearly" meant was provided) in their minds, without vocalizing; 5-) after the mental task was accomplished, proceed to the next trial by pressing the response button. Noteworthy, the participants were encouraged to be creative and instructed not to repeat the same thought across the trials. If the mental task was performed too fast (and the button was pressed within two seconds from the complete disappearance of the picture), the trial was not accepted and was repeated. The 150 trials were divided in two blocks, in one block the button presses should be performed with the right hand and, in the other, with the left hand. The order of the hands (left then right or right then left) was counterbalanced across participants. Before the experiment each individual performed a training block of 20 trials.

2.2.2. The willed condition

The sequence of events was similar to the described in the previous condition, except that no picture was presented. Instead, after the fixation point became yellow and red, it changed colour again to blue and gradually returned to black (for 1667 ms). Instead of making a creative thought, participants were instructed to fixate on the central point, wait at least two seconds and, then, press the button at will. They were instructed not to estimate the time by counting during the waiting interval and to avoid premeditating their movements, trying to act "as spontaneously as possible". If a button was pressed before the minimum waiting interval of two seconds (from the complete disappearance of the blue point), the trial was rejected and repeated. A total of 120 trials were also divided in two blocks, one for the right and the other for the left hand (for each individual, the order of the hands was the same as in automatic condition).

Importantly, if the willed blocks were performed at first, the participants could be conditioned to pay attention to their intention to move during the rest of the experiment. This fact could spoil the automatic condition, in which individuals were expected to move incidentally. For this reason, the order of the conditions was not counterbalanced across participants, the automatic condition always preceded the willed condition.

2.3. EEG acquisition and preprocessing

The impedance of EEG electrodes (64 electrodes in the 10-10 system) was kept below 20 kΩ and recording was performed at 1000 Hz (direct current mode). Signal preprocessing and data analysis were performed in Matlab® R2009a (The MathWork®). The EEG data were referenced to averaged earlobe channels and filtered with low-pass and high-pass cut-offs of 0.05 and 40 Hz (Butterworth filter, 2^{th} order, zero phase-shift). Ocular artifacts were removed from the signal using independent component analysis (ICA, infomax method available in EEGLAB) (Delorme and Makeig, 2004). Because the method relies on stationarity assumption, the ICA decomposition matrix was calculated from a copy of the EEG data which was high-pass filtered at 1 Hz.

Bipolar electrodes for electromyograph (EMG) were located over the ventral and dorsal surface of the second metacarpal of both hands (surrounding the lumbrical muscles). The EMG data were high-pass filtered with a 10 Hz cut-off and notch filtered at 60 Hz and, then, represented as unsigned values. In each trial, the movement onset was determined as the moment at which the cumulative EMG, calculated from 250 ms before the button press, reached 80% of its total value. The EEG data were epoched from −2300 ms to 500 ms with respect to the movement onset.

For each individual, the epochs from each electrode and trial were rejected if the respective z-scored peak-to-peak amplitudes surpassed 1.6. The corresponding rejection thresholds (66.18 ± 20.51 µV for OCD and 64.23 ± 25.12 µV for controls) were not different between groups ($t_{11} = 0.20$, $p = 0.843$). Trials with more than 8 rejected electrodes were entirely rejected. In the remaining trials, rejected electrodes were interpolated using spherical spline interpolation (Perrin et al., 1989). The proportion of rejected trials corresponded to 8.78% ± 5.39% and the rate of interpolated electrodes per trial was 2.22% ± 1.11%. The individual ERP curves from each condition were drawn by averaging the EEG epochs across trials.

2.4. Data analysis

The movement onset was adopted as zero reference on the time axis. The segment from −2300 to −2000 ms was used as baseline. In automatic condition, because the expectancy of a novel picture could induce mental states, such as increased arousal or motivation, that could influence the readiness potential (McAdam and Seales, 1969; Bortoletto et al., 2011), the trials immediately after the "next image" screen were not included in the analysis. For ERP analysis, three scalp regions (central medial, contralateral and ipsilateral to the moving hand) and two time intervals (200 ms before the peaks of the early and late BP) were selected according to the overall spatiotemporal features of the readiness potential. The mean BP amplitudes were compared with an analysis of variance (ANOVA) with one between-subject factor – Group (OCD and control) – and three within-subject factors – Region (contralateral, medial and ipsilateral), Time (early and late) and

Condition (automatic and willed). The *p*-values were corrected according to the Greenhouse-Geisser method. In *post hoc*, the amplitudes were compared pairwise using Tukey's test.

3. Results

3.1. Behavioural and EMG results

Regarding the latencies of movements – period in which the black fixation point remained on the screen until participant's button press –, neither means (global mean latency = 4.96 ± 2.53 ms) nor standard deviations (2.16 ± 2.05 ms) of individual latencies were significantly affected by groups ($F_{1,\ 22} = 0.14$, $p = 0.708$ for means; $F_{1,\ 22} = 0.11$, $p = 0.745$ for standard deviations), conditions ($F_{1,\ 22} = 0.60$, $p = 0.447$ for means; $F_{1,\ 22} = 0.60$, $p = 0.446$ for standard deviations) or the interaction between condition and groups ($F_{1,\ 22} = 0.22$, $p = 0.647$ for means; $F_{1,\ 22} = 0.08$, $p = 0.786$ for standard deviations). The same could be said for the mean amplitude of EMG activity ($F_{1,\ 22} = 1.27$, $p = 0.273$ for group effect; $F_{1,\ 22} = 0.67$, $p = 0.422$ for condition effect; $F_{1,\ 22} = 2.89$, $p = 0.103$ for interaction, considering the averaged potential within 200ms centred at the movement onset). The mean number of repeated trials per individual (in virtue of fast button presses) was 12 ± 11.91, not different between groups (t = 0.45, p = .660).

3.2. Readiness potential analyses

As shown by the scalp map in Fig. 2(a), the readiness potential peak was widely spread over medial and lateral central areas from which one medial and two lateral triplets of electrodes were selected: FCz, Cz and CPz (medial); FC3 or FC4, C3 or C4 and CP3 or CP4 (contralateral and ipsilateral to the movement). The movement-related potentials from these three regions (conditions and groups merged) are also displayed in Fig. 2(a). According to the curves, the readiness potential started by -2000 ms and, approximately from -500 ms, late BP could be identified by its steeper and asymmetric slope. Based on the curves, the time intervals selected to calculate the early and late BP amplitudes were, respectively, from −700 to −500 and from −200 to 0 ms.

The averaged potentials from the two time intervals (Time factor), three scalp regions (Region factor), two conditions (Condition factor) and two groups (Group factor) were compared with the mixed ANOVA. The results are summarized in Table 1. In line with the prevailing view, the readiness potential amplitudes increased from the early to the late interval ($F_{1,\ 22} = 39.20$, $p < 0.001$ for Time main effect) and this increase was less pronounced at ipsilateral sites ($F_{2,\ 44} = 4.90$, $p = 0.021$ for Region main effect and $F_{2,\ 44} = 38.51$, $p < 0.001$ for Time x Region interaction), as shown in Fig. 2(a).

The main finding of the current study was the significant Group x Condition x Time interaction ($F_{1,\ 22} = 9.90$, $p = 0.005$). The mean BP amplitudes in each condition and group are represented by errorbars in Fig. 2(b). According to the *post hoc* comparisons, this interaction could be explained by two simple effects on the late BP amplitude: first, a simple condition effect found in controls, which corresponded to greater late BP in willed compared to automatic condition ($p = 0.022$); second, a simple group effect in the willed condition, consisting of higher late BP amplitudes in controls in relation to OCD patients ($p = 0.039$). The amplitudes of late BP were not significantly affected by conditions among OCD patients ($p = 0.964$) or by groups in automatic condition ($p = 0.561$). Regarding the early time interval, no significant difference was found across groups and conditions ($p > 0.206$). The readiness potential curves from each group are presented in Fig. 3. In the same figure, the topography of the difference of late BP amplitude between conditions are displayed by the scalp maps.

Because the automatic condition always preceded the willed condition, it can be proposed that the main results were ascribed to a possible effect of time on the late BP in a specific condition and group.

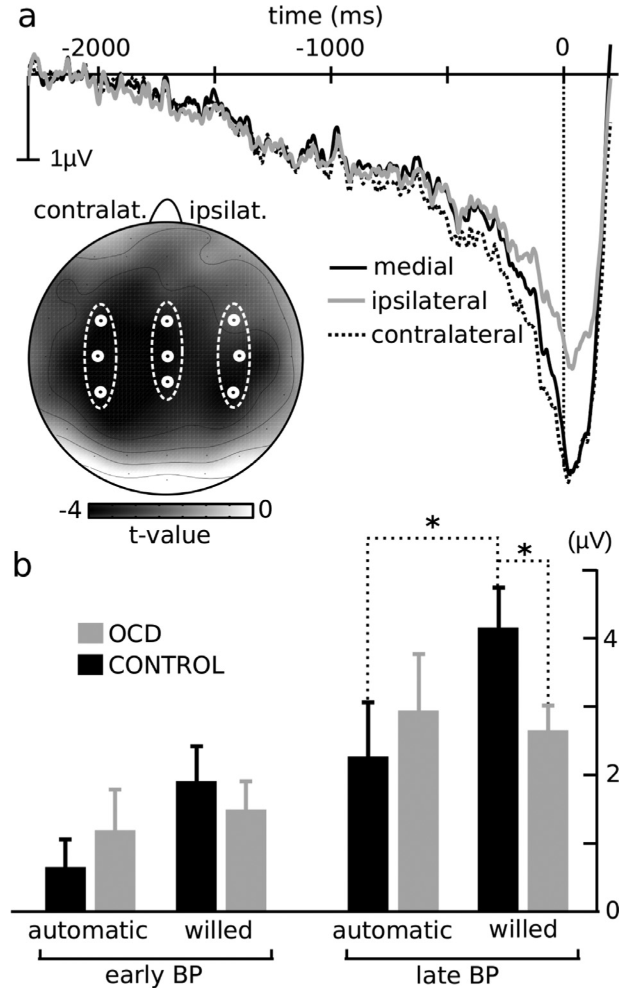

Fig. 2. Readiness potential analysis. a. Topography of the readiness potential peak (group and conditions merged) within -200 to 0 ms and the time course of the readiness potential from the selected electrodes. b. Error bars of the early BP and late BP amplitudes from each group and condition (selected electrodes merged). The asterisks indicate significant difference according to *post hoc* analysis.

Table 1
Result of the repeated-measures ANOVA.

	d. f.	*F*	*p* (Greenhouse-Geisser)
Group	1, 22	0.07	0.790
Region	2, 44	4.90	0.021**
Condition	1, 22	3.59	0.071
Time	1, 22	39.20	< 0.001**
Group x Region	2, 44	2.32	0.125
Group x Condition	1, 22	3.45	0.077
Group x Time	1, 22	0.77	0.391
Region x Condition	2, 44	1.37	0.264
Region x Time	2, 44	38.51	< 0.001**
Condition x Time	1, 22	< 0.01	0.951
Group x Region x Condition	2, 44	1.39	0.261
Group x Region x Time	2, 44	1.21	0.304
Group x Condition x Time	1, 22	9.90	0.005**
Region x Condition x Time	2, 44	1.22	0.305
Group x Region x Condition x Time	2, 44	0.77	0.464

** The analysis included Group as between subject factor, and Region, Time and Condition as within subject factors. The *p*-values were corrected according to Greenhouse-Geisser method. *P*-values less than 0.05 are highlighted with.

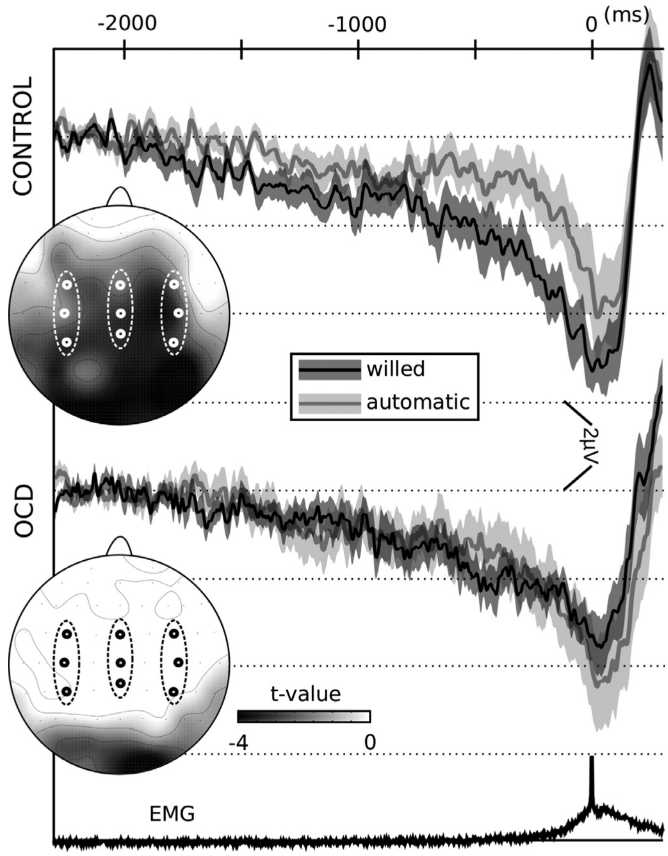

Fig. 3. Readiness potential curves: Topography of the late BP within -200 to 0 ms and the time course of the readiness potential from each group and condition.

To rule out this possibility, trial-by-trial amplitudes of the late BP from each condition and group were regressed against the ordinal position of the trials. Indeed, no linear trend of late BP amplitude was identified (unsigned linear coefficients ≤ 0.011, r-square ≤ 0.001, $F \leq 1.19$, $p \geq 0.275$).

4. Discussion

Briefly, this study evaluated the BP subcomponents associated with automatic and volitional processes of motor planning in individuals with OCD using a very simple button pressing task performed under different conditions of volitional engagement. After carefully ruling out possible potential methodological bias associated with physical parameters of button press, such as latency or intensity of muscular activity, interesting differences between the groups were observed. Briefly, individuals with OCD did not show the BP´s morphological changes observed in controls when automatic and willed conditions were compared. A detailed discussion about these results and their possible implications for the pathophysiological models of OCD is presented bellow.

4.1. The effect of conscious intention to act on the readiness potential in controls

In a previous study (Takashima et al., 2018), we found that the late BP commonly observed during self-paced movement tasks was at least partially suppressed when the participant's attention was distracted from their motor acts to a particular mental imagery exercise based on pictures. In the same study, we supported that this finding was not ascribed to the contents of the pictures, and we also proposed that further studies using similar experimental design, but with different mental tasks, (such as the current study) would be important to test the hypothesis that the modulation of the late BP was actually associated with the attention to intention to move and, thus, would be present regardless the nature of the distracting task. This hypothesis was indeed supported by the current results. Nevertheless, we acknowledge that additional studies would be necessary to completely rule out putative influences particularly associated with the employed mental tasks on the BP.

Concerning the control group, the analysis of readiness potential revealed two main findings consistent with the results of our previous study (Takashima et al., 2018). First, the magnitude of the early BP was not influenced by participants' attention to the execution of their own motor actions. Second, the attention to intention to act (and presumably the conscious intention to act) was associated with an enhanced negative slope widely symmetrically distributed over central regions which accounted, at least partially, for the expression of the late BP.

With regard to the automatic condition, it is proposed that the mental task diverted conscious brain resources (including cognitive functions, such as attention, working memory, reasoning and timing) from the planning of button presses, leading to decrease of the BP amplitude. It can be admitted that the generation of creative thoughts presents imprecise temporal relationship with the button presses and, thus, it seems very unlikely that the underlying mental processes accounted directly for the effect on the late BP (an ERP component with strict and close temporal relationship with motor acts). In accordance with earlier studies (Baker et al., 2012; Takashima et al., 2018), the analysis of button presses incidental to a main task suggests that even when individuals are paying little or no attention to their actions, it is possible to identify a slow negative wave consistent with the early BP starting approximately from 2 to 1.5 s prior to the movement´s onset. This observation supports the hypothesis that a significant part of the initial portion of the readiness potential is related to unconscious processes (Libet et al., 1993). In the willed condition, when the button presses were the focus of participants' attention (as in traditional "self-paced" movement task, behavioural paradigm most commonly used to study the readiness potential, e. g., Rektor et al., 2001; Yazawa et al., 2000; Praamstra et al., 1995), the readiness potential showed enhanced negative slope few hundreds of milliseconds before the movements, probably corresponding to cortical activities associated with the demand for volitional motor control.

Considering the limited scope of this study, the exact neurophysiological meaning of these potentials can not be adequately discussed. However, it is important to point out the ongoing discussion about whether early BP reflects subliminal cognitive functions, such as movement selection (Praamstra et al., 1995) or timing (Baker et al., 2012), or contingent fluctuation of neural activity which influences the probability of an individual acting (Schurger et al., 2012; Jo et al., 2013). Apparently, the increased late BP in the willed condition could be ascribed not only to volitional control, but also to the awareness of acting, phenomena which presumably involves related but different sets of brain processes. In addition, this discussion may become even more complex if we take into account the integrative character of consciousness, that is, its ability of establishing mutual influences between motor processes and other cognitive elements such as levels of arousal, motivation, attention, timing, and reasoning (Tononi and Edelman, 1998; Dehaene and Naccache, 2001).

Despite these methodological limitations, this experiment might allow us to discriminate motor preparatory potentials recruited prior the execution of automatic voluntary movements from those somehow associated with the conscious experience of acting. It is important to acknowledge that, combined with our previous study (Takashima et al., 2018), the current results do not suggest that brain processes associated with conscious intention are responsible for the entire late BP, but for at least part of it (mainly the medial portion). As a matter of fact, the lateral and asymmetric portion of the late BP is known to be influenced by subliminal stimuli processing (Eimer, 1999).

4.2. Automatic and volitional motor readiness in OCD

As the amplitudes of the readiness potential in the *automatic* condition showed no significant differences between groups, we admit that that motor-related potentials involved in the genesis of automatic button press were not consistently influenced by the underlying psychiatric condition. The results concerning the willed condition indicate that, during the execution of self-paced movements, individuals with OCD show reduced expression of the late BP in relation to controls. These results suggest that OCD patients present peculiar, probably attenuated, brain activities which are commonly recruited when unconscious intention to act assume conscious representation and, thus, becomes susceptible to volitional control.

Regarding current theories on the pathogenesis of the OCD, the present findings support the hypothesis that the affected individuals have an impairment concerning the manifestation of volitional control over automatic action tendencies. This hypothesis is coherent with observations that the process of switching from automatic to volitional mode of motor control relies on frontal cortico-basal ganglia networks (Isoda and Hikosaka, 2011) which are known to contribute to the genesis of readiness potential (Yazawa et al., 2000; Rektor et al., 2001). This putative deficit would be manifested even if the automatic actions are not related to obsessions or compulsions and could be observed in spontaneous responses to ordinary contextual demands. Moreover, if this deficit implies in a volitional action control dysfunction, it could also account for the difficulty presented by OCD patients in withholding prepotent responses during speeded choice tasks (Bannon et al., 2002; Chamberlain et al., 2006; Penadés et al., 2007).

The neural correlates of conscious intention to act seems damped in individuals with OCD, fact that it is compatible with evidences observed in other clinical conditions. For example, individuals with Tourette syndrome (TS), a condition marked by significant motor symptoms and frequently accompanied by OCD symptoms, have showed delayed awareness of intention to act during the performance of self-initiated movements (Moretto et al., 2011). Our results suggest that a deficiency in controlling mental or motor impulses may be associated with an impaired perception of automatic action tendencies common to both TS and OCD. Naturally, this study did not directly approach this hypothesis and additional investigations are need.

The imbalance between enhanced automatic action tendencies and insufficient mechanisms of volitional control constitutes the basis of prevalent models on the pathogenesis of the OCD (Nakao et al., 2014). Accordingly, the OCD has been consistently associated with exacerbated activity of neural circuits involved in acquisition and performance of automatic action patterns (Graybiel and Rauch, 2000). As volitional control functions play important role in modulation of automatic impulses, primary disruptions of their normal operation, as suggested by the present study, can account by the hyperactivity of neural circuits involved in acquisition and performance of unintentional behaviours and thoughts characteristic of OCD (Graybiel, 1990). In fact, according to the Hebbian learning processes models, recurrent failure to inhibit certain maladaptive actions can make the neural circuits involved in the genesis of these actions increasingly excitable and, thus, more refractory to inhibition (Rolls et al., 2008).

The interpretation of the present results in terms of dysfunction associated with volitional control corroborates neuroanatomical studies showing that individuals with OCD present structural abnormalities surrounding brain regions which are highly involved in both the genesis of readiness potential and top-down control of voluntary action. A meta-analysis of neuroimage studies using voxel-based morphometry showed that the OCD is associated with decreased grey matter volumes of dorsal mediofrontal and anterior cingulate gyri, extending to the supplementary motor area and frontal eye fields (Radua and Mataix-Cols, 2009). Furthermore, structural abnormalities in mediofrontal cortex have also been supported by reduced levels of local N-acetylaspartate (Ebert et al., 1997; Jang et al., 2006; Yucel et al., 2007).

As an alternative explanation for the present findings, one can hypothesise that regardless the experimental conditions, individuals with OCD were constantly exposed to obsessions and/or executing compulsions. If so, the absence of condition effect on the readiness potential in these individuals could be ascribed to the fact that, in both conditions, they were equally distracted from their intention to move. In this way, the putative deficit associated with volitional activities would be secondary to the OCD symptoms instead of being a primary cognitive dysfunction. Although we did not evaluate the patients with respect to their symptoms during the experiment, it is noteworthy that the similar button press latencies in both groups argues against the hypothesis that the OCD participants had significantly increased cognitive loads prior to button presses.

Regarding the automatic condition, the hypothesis that individuals with OCD have increased impulsivity for any generic automatic actions, manifested as increased or steeper readiness potential, was not corroborated by the present results. We consider three possibilities for explaining why readiness potential in the automatic condition showed no differences between groups. First, the difference exists but was not detected due to our relatively small sample size. Second, OCD could not be associated with enhanced action tendencies, at least when the actions are not related to obsessions, compulsions, or emotional contexts. Third, if OCD is associated with enhanced action tendency, this phenomenon is not manifested through the readiness potential.

Concerning previous studies on motor preparatory potentials in OCD, Dayan et al. (2017) found increased readiness potential´s amplitudes in individuals with OCD, which the authors ascribe to enhanced action tendencies related to the psychiatry condition. The direct comparison between their results and the findings reported in this study is limited for the some reasons. Dayan et al. analysed readiness potentials concerning choice reactions, whose amplitudes were concomitant with the motor responses, by 400 ms from imperative go stimuli in "go-nogo" and "stop-signal" tasks. Thus, their results were probably not related to stages of motor preparation not influenced by response inhibition, as claimed. Instead, by probing the output of response selection process, their findings possibly reflected abnormal influence of stimulus processing on the readiness potential, including lack of response inhibition. In fact, components of the readiness potential associated with choice reactions may correlate with online response activation during response selection process (Eimer, 1997). Furthermore, by analysing the overall readiness potential, instead of the lateralized readiness potentials from stimulus-locked epochs, their findings could also be ascribed to non-motor ERP components such as the P300.

Finally, it is important to acknowledge that our patient sample did not represent the overall population of individuals with OCD, but predominantly a highly symptomatic and treatment-refractory subset. Thus, it is possible that our findings concern specifically more severe cases of the disorder. Also, because virtually all patients were receiving serotonin selective reuptake inhibitors, putative influences of these drugs on the results could not be completely ruled out.

In conclusion, this study found evidences that the increasing of late BP associated with the attention to, and presumably the awareness of, intention to move observed in normal controls is not observed in individuals with OCD. Based on current pathophysiological theories, this finding suggests that brain activities associated with the establishment of volitional motor control over automatic action tendencies is somehow impaired in individuals with OCD.

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