International Journal of Psychological Studies; Vol. 11, No. 2; 2019
ISSN 1918-7211 E-ISSN 1918-722X
Published by Canadian Center of Science and Education

Delayed Response Improves Inhibitory Control in Low- and High-Impulsivity Adolescents: Effects of Emotional Contexts

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Received: January 15, 2019 Accepted: March 25, 2019 Online Published: March 26, 2019

doi:10.5539/ijps.v11n2p42 URL: https://doi.org/10.5539/ijps.v11n2p42

Abstract

The purpose of this study was to identify the effects of delayed response on inhibitory control in low- and high-impulsivity adolescents in the presence of an emotional context. Participants performed a Go/No-Go task in 4 conditions: a control context with and without delayed response, and a pleasant context with and without delayed response. The amplitudes and latencies of the N2 and P3 components were evaluated. The delay increased the number of correct inhibitions and omissions but decreased the number of correct responses and N2 and P3 amplitudes during inhibition. The high-impulsivity adolescents showed larger amplitudes in P3NoGo but shorter N2 latencies during the NoGo trials, and the opposite during the Go trials, as they required more processing time than the low-impulsivity adolescents to restart their motor responses. In conclusion, the delayed response did improve inhibitory control and, the beneficial effects of the delay were less pronounced in the high-impulsivity adolescents when the distraction of the pleasant stimuli was present.

Keywords: delayed response, impulsivity, inhibition, emotion, adolescence, ERP

1. Introduction

Adolescence is a transitional developmental stage from childhood-to-adulthood marked by major changes that include sexual maturation, cognitive improvement, emotional instability and greater social involvement with peers. It is also characterized by increased impulsivity and risk-taking behavior, more pronounced responses to rewarding and emotional stimuli, higher novel sensation-seeking, and poor judgment in goal-directed behaviors, though these traits are by no means expressed homogeneously in all teenagers (Casey, Jones, & Hare, 2008; Chambers & Potenza, 2003; Romer, 2010). This lack of homogeneity may reflect individual differences in top-down control (prefrontal striatal circuit) and bottom-up (ventral striatal circuit) systems imbalance, which can exacerbate emotional reactivity and so increase poor outcomes in some adolescents (Casey et al., 2008; Hare et al., 2008).

Impulsivity is a significant feature of adolescence that is defined as a predisposition to perform rapid, unplanned reactions to internal or external stimuli with little regard for the potential negative consequences of these reactions that might affect the impulsive individual or others (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001). Impulsivity also implies difficulty in inhibiting a behavioral or cognitive response and in delaying gratification (Dimoska & Johnstone, 2007).

Behavioral regulation is linked to the executive functions in general and, specifically, to inhibition (Barkley, 1997), a core process that includes cognitive and motor inhibition, as well as interference control (Nigg, 2000). Inhibiting motor behavior entails suppressing unwanted, prepotent or reflexive actions, while interference control implies the ability to resist interference from irrelevant or misleading information in order to solve a task properly. Although everyday life events suggest that adolescents have lower inhibitory control, particularly in the presence of emotional stimuli, few studies have evaluated this cognitive function in this population. Inhibitory abilities tend to improve from childhood to adulthood, but when emotional information is involved some shortcomings are observed during adolescence. Somerville, Hare and Casey (2011), for example, reported that in the presence of positive emotional stimuli adolescents commit more false responses than children or adults. Cohen-Gilbert and Thomas (2013), meanwhile, observed that response inhibition is more easily disrupted by negative emotional distractions in early adolescence compared to late adolescence or early adulthood. Other authors (Tottenham, Hare, & Casey, 2011) have found that while response times to negative emotional stimuli are faster in male adolescents than children and adults, when the former must restrain their responses, they seem to employ a strategy that slows down their response time in order to achieve this. The difficulties that teenagers exhibit in inhibitory control may improve as a function of the time allowed to respond, given that some studies have found that longer times to prepare the response prolong reaction times but result in fewer inhibition errors (Band, Ridderinkhof, & van der Molen, 2003; Benikos, Johnstone, & Roodenrys, 2013; Jodo & Kayama, 1992). Hence, a brief interval to prepare responses (delayed response) might improve motor inhibition, particularly in the presence of emotional stimuli that may be difficult for adolescents to regulate adequately.

One widely-used technique for studying neural activity related to cognitive processes consists in recording event-related potentials (ERPs), due to their high temporal resolution. The main ERP components associated with inhibitory processes are N2 and P3, whose amplitudes and latencies are, respectively, indices of neural activity and of the processing time involved in restraining motor responses (Bokura, Yamaguchi, & Kobayashi, 2001; Falkenstein, Hoormann, & Hohnsbein et al., 1999; Folstein & van Petten, 2008; Jodo & Kayama, 1992). N2 is a negative component that reaches its maximum amplitude between 200 and 350 ms. It has been related to cognitive control, including response monitoring, action control, response restraint, the detection of novel stimuli, and the orientation of visual attention (Folstein & van Petten, 2008). Some studies support an association between N2 amplitudes and the ability to inhibit a prepotent response (Falkenstein et al., 1999) and the degree of difficulty of the inhibition (Jodo & Kayama, 1992). P3, in contrast, is a positive component that peaks between 300 and 600 ms, and has been related to context updating (Donchin & Coles, 1988), task demands (Polich, 2007), and response inhibition (Wessel & Aron, 2015).

With respect to the interference effects of emotional contexts, Albert, López-Martin and Carretié (2010) reported larger P3NoGo amplitudes in a positive context compared to a negative one, concluding that motor inhibition is more difficult in positive than negative contexts because pleasant stimuli are more attractive than unpleasant ones, and so require greater response control. Other studies have shown that the interference effects of implicit emotional contexts on response inhibition seen in adults are even higher in adolescents. In the former, enhancement of N2NoGo amplitudes was found in the presence of unpleasant contexts compared to neutral and pleasant ones (Ramos-Loyo, Angulo-Chavira, Llamas-Alonso, & González-Garrido, 2016). Adolescents showed similar effects on N2 amplitudes during response inhibition when an unpleasant context was present, but on both Go and NoGo trials (Ramos-Loyo, Llamas-Alonso, & González-Garrido, 2017). These studies demonstrate that response inhibition is affected by implicit emotional contexts that could be reflected in ERPs.

In summary, we know that adolescents show greater difficulty in response inhibition than adults, particularly when implicit emotional contexts are present, and that this phenomenon can be observed in ERPs. This difficulty could be modulated by impulsivity traits. Evidence indicates that increasing the time to prepare a response improves inhibitory control and that this may depend on impulsivity traits. Therefore, the aim of this study was threefold: to evaluate whether delaying the response benefits motor inhibition in adolescents; to identify differences in motor inhibition between low- and high-impulsivity adolescents; and to ascertain whether an implicit pleasant context interferes differentially with inhibitory control in these two groups of teenagers. We hypothesized that inducing the delay in responses would improve inhibitory control by providing more time for response preparation, thus allowing modulation of the saliency of the emotional stimuli. We further assumed that the high-impulsivity participants would have greater difficulty in motor inhibition than those with lower impulsivity, especially in the presence of pleasant contexts.

2. Method

2.1 Participants

Participants were chosen based on their total scores on the Barratt Impulsiveness Scale (BIS-11) adapted for Spanish-speaking adolescents (Chahin, Cosi, Lorenzo-Seva, & Vigil-Colet, 2010), and classified as having low- (LI) or high-impulsivity (HI). We applied the BIS-11 to 210 male adolescents (aged 16-17). The lowest score obtained was 16 and the highest was 98 (x =51, SD= 11). The adolescents who obtained scores from 34 to 46 were included in the LI group, while those who scored from 56 to 71 were assigned to the HI group. Adolescents with ±.5 standard deviations from the mean were excluded in order to establish a difference of one standard deviation between groups. Those with extreme scores (i.e., more than 2 standard deviations from the mean) were excluded because this could indicate abnormal behavior. Seventeen adolescents with low-impulsivity scores and twenty with high-impulsivity scores were subjected to EEG recording. Some participants were excluded because of EEG artifacts or low performance (below 50% of correct inhibitions), so the final LI group included 13 participants and the HI group had 14 participants. All subjects were healthy, right-handed, male teenage volunteers (aged 16-17 years, 11 months, x=16.60 SD=.49) selected from public high schools. Males were selected for the study because they are more prone to impulsivity than females (Weafer & de Wit, 2014). All subjects fulfilled the following criteria: normal estimated IQ scores (vocabulary and cubes, WAIS-III, Weschler, 1997), no history of neurological or psychiatric conditions, and no consumption of substances of abuse (clinical interview). Also, to further characterize the groups, the Attention-Deficit Disorder Scales for Adolescents and Adults was applied (ADD, Brown, 1996). The teenagers received a monetary compensation for their participation. All subjects and their parents signed an informed consent form. The study was approved by the Ethics Board of the Institute in accordance with the terms of the Helsinki Declaration.

Table 1. Characteristics of the sample. Impulsivity levels (BIS-11) and ADHD scores (ADD Brown, 1996).

BIS-11	**Group**	$\bar{X}$	***SD***	***t***	***p***
Total scores	LI	43	2.4	15.7	.0001
	HI	61	3.4		
Motor impulsivity	LI	13	2.3	2.59	.01
	HI	16	4.1		
Attentional impulsivity	LI	15	3.2	3.68	.001
	HI	21	4.7		
Non-planning impulsivity	LI	13	2.2	8.06	.0001
	HI	24	4.3		
Add Brown	LI	32	14	1.09	.05
	HI	44	16		
IQ	LI	104	8	.04	.96
	HI	104	10		

Note. LI= low-impulsivity, HI= high-impulsivity, SD= standard deviations, IQ= Intelligence quotient estimates

2.2 Task and Experimental Procedure

Figure 1 shows the Go/NoGo task paradigm used. The target stimulus consisted of a red or green arrow (1.90° visual angle) presented in the center of a computer screen with a red or green bar at the right or left edge of the screen, using e-Prime software. Participants were asked to press a button on a keyboard when the arrow pointed to the bar and coincided with its color (Go), but to withhold their response when it did not (NoGo). Simultaneously, either a control or a pleasant image was shown in the background (16.70° visual angle) according to the task condition. For the pleasant context, 42 emotional stimuli from the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 2008) were presented (valence X= 6.58, SD=0.63; arousal X= 5.72, SD=0.77). For the control context, those same images were scrambled to form the background. Participants performed the Go/No-Go task under 4 independent conditions: control context without delayed response; control context with delayed response; pleasant context without delayed response; and pleasant context with delayed response. For the control and pleasant no-delay inhibition conditions, the stimulus was shown for 300 ms, followed by a black screen. The inter-stimuli interval varied randomly between 1700 and 2000 ms. For the control and pleasant delay response conditions, the task was identical except that a warning tone indicated when the participant was to respond. The tone sounded after a delay of 700-1000 ms following the presentation of the stimulus to allow the participant more time to either prepare, or inhibit, his response. Subjects were instructed to respond as quickly and correctly as possible. Each condition consisted of 240 trials, 75% Go and 25% NoGo. The order of presentation of the different conditions was counterbalanced among subjects. Before beginning EEG recording, participants completed a practice session of 120 trials with no context to ensure that they fully understood all instructions. The following behavioral responses were measured: percentage of correct responses, correct inhibitions and omissions, and reaction times. Reaction times for the delay trials were measured from the moment that the tone signal sounded.

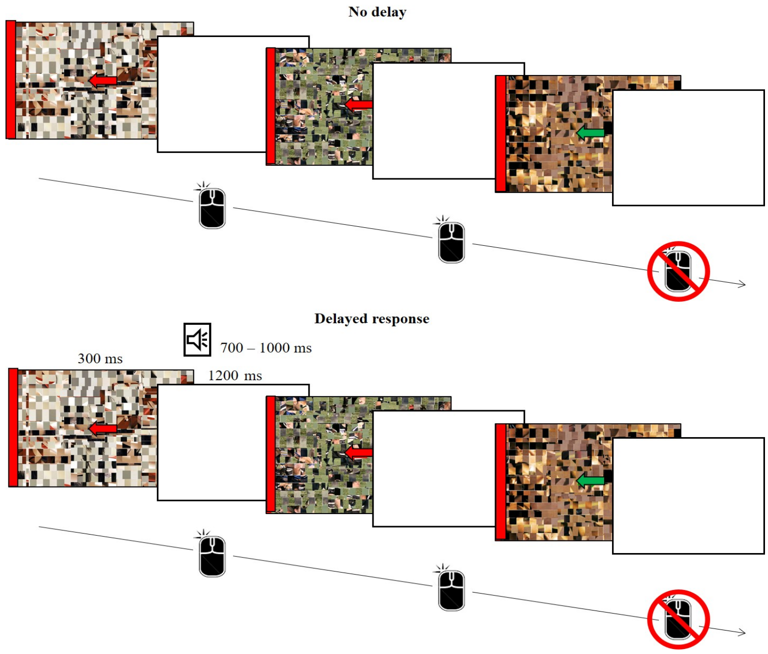

Figure 1. Experimental Go/NoGo task design. Subjects had to press a key when the arrow coincided in both direction and color (red, green) with the bar, but withhold their response when it did not match. In the delay response condition, a warning tone indicated when the participant was to respond.

2.3 Electroencephalographic Recordings

Participants were seated comfortably in a dimly-lit, electrically-shielded room. EEGs were recorded continuously during task performance using a 128-channel Medicid 5 device (Neuronic) at Fp1, Fpz, Fp2, AF7, AF8, AF3, AF4, F3, Fz, F4, FC1, FC2, FC5, FC6, T7, T8, C3, Cz, C4, P3, Pz, P4, P7, P8, O1, Oz and O2, according to the extended 10-20 International System, using linked earlobes as reference (cut-off filters .05-30 Hz) and a sampling rate of 500 Hz. Electrode impedances were kept below 5 KOhms. Electro-oculograms (EOG) were also recorded from electrodes placed bilaterally in the supraorbital and infraorbital eye regions to eliminate segments contaminated by eye-movement artifacts.

2.4 Data-Processing

Twenty artifact-free epochs, time-locked with stimuli onset from the Go and NoGo trials were averaged independently to obtain the ERP components. The number of epochs was equal for all subjects and conditions. Only epochs that corresponded to correct responses and correct inhibitions were included in the analysis. During the delayed response task, trials in which the response was made before the auditive signal stimulus sounded were discouraged. Each epoch lasted 1000 ms, including the pre-stimulus interval (100 ms), which was used to determine baseline. Time windows were identified by visual inspection of the grand average ERP waveforms: N2, 150-250 ms, and P3, 300-600 ms. Figure 2 shows the grand mean ERPs for the Go and NoGo stimuli across groups and conditions. As can be seen, an N2 component is apparent around 200 ms mainly in the fronto-central locations; whereas P3 peaked at approximately 450 ms and was more evident in parietal areas for the Go trials, but in fronto-central locations for the NoGo trials. The amplitudes and latencies of each component peak were measured from individual ERP averages at the midline electrodes (Fz, Cz, Pz), where the maximum amplitudes were seen, and coincide with the locations mentioned in the literature (Bokura et al., 2001; Folstein & van Petten, 2008; Polich, 2007; Ramos-Loyo et al., 2017).

2.5 Statistical Analysis

To test behavioral performance (*i.e.*, percentage of correct responses, correct inhibitions and omissions, and reaction times for the Go trials), mixed ANOVAs (groups × conditions × contexts) were conducted. In order to confirm that the N2 and P3 components behaved as expected for a Go/NoGo task, a first global analysis was conducted to compare the Go and NoGo trials at the electrode sites evaluated (Fz/Cz/Pz) with the average of control and pleasant contexts in the no-delay condition.

Afterwards, the N2 and P3 amplitude and latency values were evaluated by a 4-way mixed ANOVAs (groups: LI/HI; conditions: delay/no-delay; contexts: control/pleasant; electrode sites: Fz/Cz/Pz) for both the Go and NoGo trials. Significance was established at $p<0.05$ and significance levels were adjusted using Greenhouse-Geisser epsilon correction. Corrected *p*-values are reported. Post hoc tests for pairwise comparisons with Bonferroni correction were used to adjust significance levels. Pearson's correlation analysis was performed to further explore potential associations between reaction times and the percentage of correct inhibitions, and between delay duration and the percentage of correct responses, correct inhibitions and omissions.

3. Results

3.1 Behavioral Measures

Behavioral results are summarized in Table 2. No significant between-group differences were found. In the delay condition, the percentage of correct inhibitions increased in both groups $(F\ (1, 25) = 46.53,\ p < .001,\ \eta_p^2 = .65)$, but omissions did as well $(F\ (1, 25) = 50.79,\ p < .001,\ \eta_p^2 = .67)$, while the percentage of correct responses decreased $(F\ (1, 25) = 46.53,\ p < .001,\ \eta_p^2 = .65)$ compared to the no-delay condition. As expected, reaction times were lower with the delayed response $(F\ (1, 25) = 43.80,\ p < .0001,\ \eta_p^2 = .62)$. In the no-delay condition, higher reaction times correlated with the percentage of correct inhibitions in the control $(r=.78,\ p=.001)$ and pleasant contexts $(r=.68,\ p=.001)$. Also, the duration of the delay correlated positively with the percentage of correct inhibitions $(r=.43,\ p=.01)$ and omissions $(r=.48,\ p=.01)$.

Table 2. Means and standard deviations (SD) of the behavioral measures for the low- (LI) and high-impulsivity (HI) groups.

	Correct inhibitions (%)		**Correct responses (%)**		**Omissions (%)**		**Reaction times (ms)**	
	LI	**HI**	**LI**	**HI**	**LI**	**HI**	**LI**	**HI**
Control no-delay	71.28 (14.20)	80.60 (16.20)	98.29 (2.0)	98.02 (4.10)	1.78 (0.53)	2.30 (0.80)	525 (122)	583 (196)
Control delay	92.82 (2.48)	90.10 (8.60)	80.12 (9.5)	72.28 (21.60)	12.22 (2.50)	23.85 (3.90)	154 (55)	193 (92)
Pleasant no-delay	71.15 (14.32)	79.10 (13.40)	98.97 (1.90)	99.04 (1.70)	1.20 (0.50)	.80 (0.30)	531 (114)	575 (138)
Pleasant delay	91.92 (2.34)	90.10 (8.10)	84.44 (11.70)	78.41 (16.30)	15.00 (3.07)	19.80 (4)	152 (57)	176 (79)

3.2 ERPs

Grand mean ERPs for the Go and NoGo stimuli across groups and conditions for each context are displayed in Figure 2, while Figure 3 presents scalp distribution maps for each component. N2 and P3 amplitude and latency values in each condition for HI and LI are presented in Tables 2 and 3 (Appendix A).

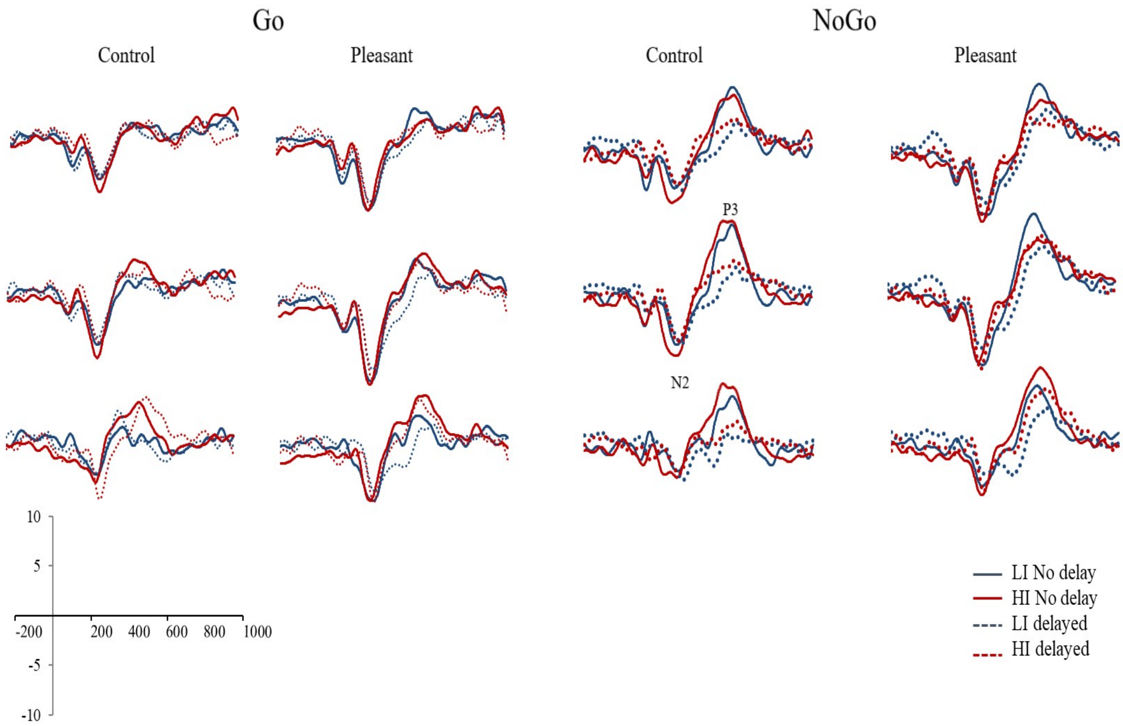

Figure 2. **G**rand mean ERPs for the Go and NoGo stimuli across groups, high- (HI) and low-impulsivity (LI), and conditions for each context are displayed.

3.2.1 Differences between Go and No-Go Trials

An interaction of trials × electrode sites *(F (2, 52) =5.57, p=.01,* η_p^2*=.17)* indicated that the amplitude of N2 showed a frontocentral distribution with higher values at Fz than Pz (p=.008) and at Cz than Fz (p=.004) and Pz (p=.0001) in the NoGo trials. P3 amplitude was higher *(F (1, 26) = 20.48, p=0.0001* η^2_p*=.44)* in the NoGo than the Go trials.

3.2.2 Differences between the Delay and No-Delay Conditions

Amplitudes. N2 responded to the delay by reducing its amplitude during Go trials (*F (1, 25) =4.63, p=.04,* η_p^2*=.15).* In the NoGo trials, an interaction of delay × electrode sites (*F (2, 50) =12.83, p=.0001,* η_p^2*=.33)* also indicated lower amplitudes in the delay than the non-delay conditions at Fz (*p*=.02) and Cz (*p*=.006). Similarly, regarding P3, a main effect indicated that introducing a delay reduced amplitudes, though this was only evident on the NoGo trials (*F (1, 25) =17.51, p =.001,* η_p^2*=.41)*.

Latencies. N2 latency showed no differences between delay and no-delay, but P3 latencies were longer in the delay than the no-delay condition (interaction of delay × electrode sites, *F (2,50) =5.87, p=.005,* η_p^2*=.19*) on the Go trials at Fz (*p=.002*).

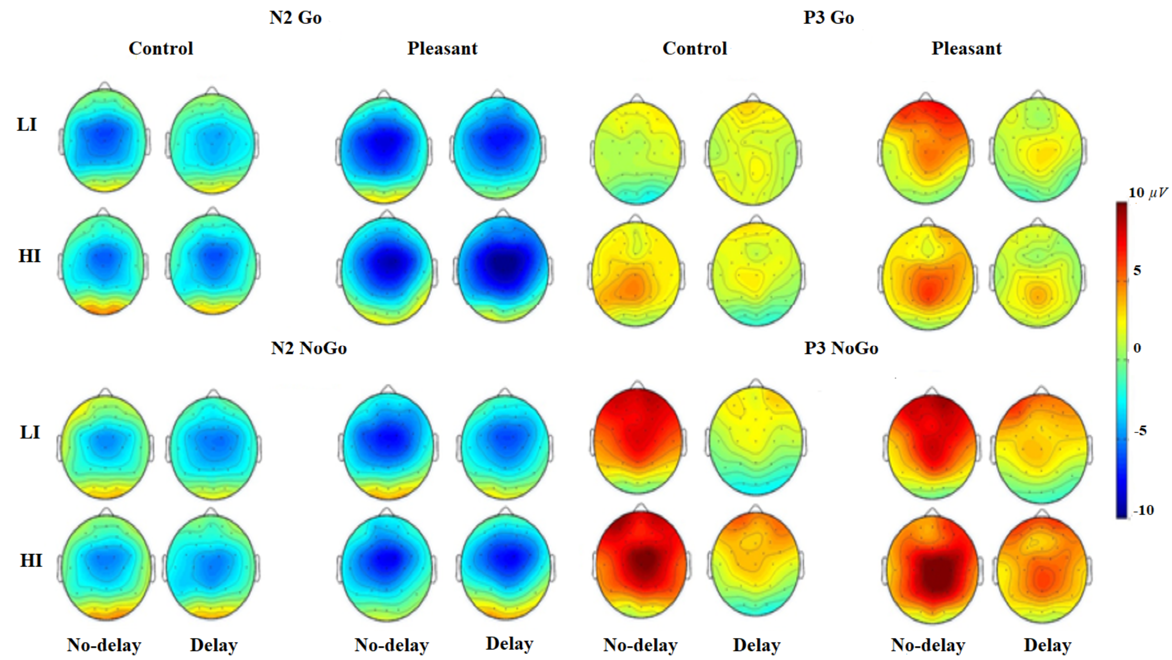

Figure 3. Topographical distribution of ERPs. The color scale represents N2 and P3 microvolt values. In the case of N2, blue corresponds to maximum negativity, while for P3 red corresponds to the highest positivity.

3.2.3 Between-Group Differences

Amplitudes. No significant main effect for groups was found for N2 amplitudes. As an overall effect, P3 amplitudes were higher in HI than LI $(F\ (1, 25) = 7.36,\ p = .01,\ \eta_p^2 = .22)$ and an interaction of groups × conditions × contexts ($F\ (1, 25) = 5.55,\ p = .02,\ \eta_p^2 = .18$) indicates that the highest amplitudes in HI were observed in the control context without delay ($p = .004$) and in the pleasant condition with delay ($p = .02$). Also, an interaction of groups × context × electrode sites $(F\ (2, 50) = 5.15,\ p < .009,\ \eta_p^2 = .17)$ showed that HI displayed higher amplitudes than LI in the pleasant context on the NoGo trials at Pz ($p = .03$).

Latencies. Regarding N2 latency, HI showed longer values than LI (interaction groups × conditions × electrode sites, $F\ (2, 50) = 7.62,\ p < .001,\ \eta_p^2 = .23$) in the delay condition at Pz ($p = .01$) during the Go trials. During the N2NoGo trials, HI had shorter latencies than LI (interaction groups × electrode sites, $F\ (2, 50) = 3.57,\ p < .03,\ \eta_p^2 = .12$) in Cz ($p = .03$). No differences were observed at P3.

3.2.4 Differences between Contexts

Amplitudes. N2 amplitudes showed higher values in the pleasant than the control context on both the Go $(F\ (1, 25) = 25.55,\ p = .0001,\ \eta_p^2 = .50)$ and NoGo trials $(F\ (1, 25) = 22.93,\ p = .0001,\ \eta_p^2 = .47)$.

Latencies. The latency of the N2 component showed higher values in the pleasant context than the control one $(F\ (1, 25) = 13.12,\ p = .001,\ \eta_p^2 = .34)$ on the Go trials. Similarly, in the case of P3 during Go $(F\ (1,25) = 23.69,\ p = .001,\ \eta_p^2 = .50)$ and NoGo trials $(F\ (1,25) = 17.20,\ p = .0001,\ \eta_p^2 = .40)$, latencies were longer in the pleasant than the control context.

4. Discussion

The main objective of this study was to evaluate the effects of a delayed response on inhibitory control in low- and high-impulsivity adolescents in the presence of an emotional context. Results indicate that delaying the time allowed to respond improved response inhibition and modulated the amplitudes and latencies of the ERP components. In addition, both low- and high-impulsivity adolescents showed differences in ERPs that were modulated by context.

Similar to our findings, other studies have observed that inhibitory control improves when a higher response time is allowed (Benikos et al., 2013; Jodo & Kayama, 1992), though the number of correct responses decreased, and the number of omissions increased. These measures correlated positively with delay duration, leading us to suggest that while delaying the motor response enhanced inhibitory control, it also made it more difficult to respond to the targets as the delay duration increased. These effects could be explained using Logan and Cowan's horse race model (1984) that has been tested in the stop-signal reaction task paradigm (SSRT), which proposes that response and inhibition are independent processes, and that a signal can initiate a stopping process that races against the motor response process. In this model, if the stopping process wins, the action will be inhibited, but if the response process wins, it will be completed. Moreover, it seems that when a stopping process is established globally, inhibition wins the race and makes it difficult to reinstate the motor response. This model could explain our results, given that delaying the motor response improved inhibition but diminished the ability to respond.

The effects of delaying the response were also seen in the N2 and P3 amplitudes and P3 latencies. N2 amplitude diminished with the delay on both Go and NoGo trials, perhaps indicating that lower top-down attentional control was required to accomplish both response and response inhibition, since the N2 amplitude increased with greater task difficulty (Benikos et al., 2013; Jodo & Kayama, 1992). Also, P3NoGo showed lower amplitudes in the delay than the no-delay condition, perhaps indicating that lower neural requirements were needed for inhibitory response processing, since the frontocentral P3NoGo has been related to the later stage of motor response inhibition linked to frontal lobe activity (Bokura et al., 2001; Kok, Ramautar, De Ruiter, Band, & Ridderinkhof, 2004; Smith, Johnstone, & Barry, 2007). Evidence shows that the P3NoGo amplitude decreases when participants are allowed a longer response time, and that this is associated with lower task difficulty (Benikos et al., 2013). In addition to the reduction of the N2 and P3 amplitudes, longer P3 latencies were observed in the delay condition on the response trials. These data indicate that the processing time required to give a response increased. Taken together, our ERP and behavioral findings suggest that inhibitory mechanisms may have been strengthened in the delay condition, which could propitiate a balance between activation-inhibition that is disrupted during adolescence.

In other findings, no differences were observed in the behavioral data between the low- and high-impulsivity groups, though this has occurred in other studies (Dimoska & Johnstone, 2007; Lijffijt et al., 2004; Rodríguez-Fornells, Lorenzo-Seva, & Andrés-Pueyo, 2002). It is noteworthy that while all participants were healthy high school students classified as having low- or high-impulsivity, they did not have extreme impulsivity scores that could be related to abnormal behavior. However, our high-impulsivity group did manifest higher ADHD traits than their low-impulsivity counterparts, which concurs with the impulsivity traits. Also, upon considering the total scores on the Barratt Scale to classify participants, the three impulsivity dimensions evaluated –cognitive, motor and unplanned impulsivity– showed significantly higher values in the high- than the low-impulsivity group.

Although we did not observe significant behavioral differences, the ERPs did indicate differences in brain activity between the groups, as the HI adolescents displayed higher P3 amplitudes on both the inhibition and response trials. This result may be related to the greater requirement for attentional resources to process information and select responses. These data are in line with those from Dimoska and Johnstone (2007) who also observed higher P3 amplitudes on successive stop-signal trials in high- compared to low-impulsive adults and interpreted this as an enhanced inhibitory activation in the former as a means of achieving similar behavioral performance to that of the latter. This interpretation agrees with results from another study (Ramos-Loyo et al., 2016), which found that men with higher P3NoGo amplitudes had fewer correct inhibitions in the presence of emotional contexts. However, the higher P3NoGo amplitudes in our HI group were observed mainly in the no-delay condition. When a delay was introduced, between-group differences persisted only in the pleasant condition, since the reduction in P3 amplitudes was less prominent in HI. Hence, it is reasonable to infer that the beneficial effect of the delay was less pronounced in the HI group because of the distracting impact of the pleasant stimuli during inhibitory processing.

Contrary to our results, Ruchsow et al. (2008) found a lower P3NoGo component in HI participants. However, this discrepancy could be related to the characteristics of the respective study samples, since their participants were adults. Age-related differences may well be expected because adolescents have been shown to exhibit increased neural activation in widely-distributed areas compared to adults during inhibition, which may be associated with an immature neural system (Braet et al., 2011). In addition, they established the division between low- and high-impulsivity groups according to a reaction time index on a mixed Flanker and Go/NoGo task. Another explanation of these differences in P3 results could involve intelligence, though Ruchsow et al. (2008) did not consider possible differences in intellectual ability between groups. In this respect, other authors (Russo, de Pascalis, Varriale, & Barratt, 2008) have found that lower P3 amplitudes in high- compared to low-impulsivity participants disappeared upon controlling for individual differences in mental ability. In our study, the IQ scores for the LI and HI participants were comparable.

In addition to the higher P3 amplitudes, the HI adolescents displayed shorter N2 latencies than LI on the NoGo trials at Cz. This indicates less time to process the response inhibition, which in a previous study correlated directly with lower inhibitory efficiency (Ramos-Loyo et al., 2016). Furthermore, the positive correlation between reaction times and correct inhibitions found in the no-delay condition indicates that if the adolescent takes longer to decide whether or not to respond, his ability to inhibit a prepotent response increases. However, when the delay was introduced the opposite occurred, as the HI adolescents required more time to restart their motor response system, as supported by the longer N2 latency in the delay condition during the response trials. These results could support the hypothesis that the stopping process is strongly-established in those teenagers, making it more difficult for them to reinstate their motor response when a delay response is introduced, as proposed by Logan and Cowan's horse race model (1984) discussed above. The ERP differences between our two groups may suggest that the weaker top-down control and increased emotional reactivity commonly found during adolescence, associated with a reduced functional connectivity between the ventral prefrontal cortex and amygdala (Hare et al., 2008), could be more evident in high- than low-impulsivity adolescents. This may indicate a reduced modulation between activation and inhibition in relation to task demands in the HI adolescents.

Finally, although the pleasant context did not worsen performance, we corroborated the effects of implicit emotional contexts on brain activity because the ERPs showed a higher amplitude and longer latency in the N2 component, as a main effect, in the presence of the pleasant pictures compared to the control ones. These findings coincide with those from previous studies conducted in adults and adolescents (Ramos-Loyo et al., 2016; Ramos-Loyo et al., 2017). The difference between adults and adolescents in those studies was that in the former the effects were observed only on the inhibitory trials, while the latter showed an overall effect on both response and inhibitory trials. The enhancement of N2 amplitudes in the pleasant context compared to the control one may indicate that processes such as attentional control, conflict resolution, inhibition and response-monitoring associated with the N2 component (Bokura et al., 2001; Bruin & Wijers, 2002; Folstein & van Petten, 2008; Géczy, Czigler, & Balázs, 1999) may be impaired in adolescents by the presence of emotional stimuli.

In line with the enhancement effects of N2 amplitudes of emotional stimuli, other authors have found similar results in adults (Albert et al., 2012; Buodo, Sarlo, Mento, Messerotti-Benvenuti, & Palomba, 2017). The data from our study also support the idea that the enhancement of N2NoGo is related to greater task difficulty (Jodo & Kayama, 1992; Benikos et al., 2013). In addition to the modulation of N2 amplitudes, longer N2 and P3 latencies were observed when a pleasant context was present, which indicates longer processing time. In the present study, participants had to inhibit the interference from the emotional distracter while also inhibiting the prepotent response. In this sense, task difficulty increased, provoking enhancement of the N2 amplitude and prolongation of latency in both components. In summary, it is possible that the greater saliency of the pleasant context biased adolescents' attention by inducing greater recruitment of attentional resources in order to achieve both response preparation and response inhibition. This effect could be attributed to the enhanced activation of sub-cortical regions in the presence of affective stimuli that might not be regulated efficiently due to the incomplete maturation of the prefrontal cortex in adolescence (Casey et al., 2008).

5. Conclusions

The contribution of this study consists in providing evidence that a delayed response benefits inhibitory control in adolescents regardless of their impulsivity level. However, the beneficial effect of the delay was less evident in the high-impulsivity group because of the distracting impact of the pleasant stimuli during inhibition processing. Also, the high-impulsivity adolescents showed lower modulation in brain activity in relation to task demands.

Our findings also highlight the urgent need to improve our understanding of individual differences among adolescents regarding impulsivity traits, and of the difficulties they exhibit in regulating their behaviors, especially in emotionally-salient situations. Moreover, these results may provide clues to possible applications of delaying adolescents' responses to improve their inhibitory control and, hence, modulate the impulsive actions that so often derive in risk-taking behaviors.

Some limitations of the present study concern the sample composition, as it included only healthy male adolescents. Future studies need to test the effects of delaying responses on larger samples and other populations characterized by extreme impulsivity, as well as in populations with psychiatric disorders in which impulsivity is a core feature, such as addictions, ADHD or Borderline Disorder. Also, studies with women should be considered, since both impulsivity levels and the effects of emotional stimuli seem to show gender-related differences. One final issue is that our study evaluated impulsivity traits through self-report scales filled out by the participants, so there could be a subjective slope that may lead to errors in group classification.

Images used from IAPS: 2389, 8161, 8370, 4006, 4220, 4641, 5480, 8179, 8461, 4007, 4225, 4653, 5621, 8180, 2018, 4008, 4250, 4668, 5623, 8186, 2019, 2030, 4085, 4325, 4680, 8030, 8208, 2034, 4090, 4599, 4687, 8040, 8250, 4002, 4130, 4150, 4611, 4698, 8041, 8260, 4003, 4619.

Acknowledgment

This work was supported by CONACYT grant #155520. The authors thank Paul Kersey for reviewing language use.

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