The Late Positive Potential: A neural marker of the regulation of emotion-based approach-avoidance actions?

Susan Bamford^a, Samantha J. Broyd^{a,b,1}, Nicholas Benikos^a, Robert Ward^c, Jan R. Wiersema^d, Edmund Sonuga-Barke^{a,d}.

a. School of Psychology, University of Southampton, UK.

b. Centre for Psychophysics, Psychophysiology and Psychopharmacology, School of Psychology, University of Wollongong, Wollongong, NSW, Australia

c. Wolfson Centre for Clinical and Cognitive Neuroscience, Bangor University, Bangor, UK

d. Department of Experimental Clinical & Health Psychology, Ghent University, Belgium

Corresponding Author:

Susan Bamford: susiebamford@hotmail.com

School of Psychology,

University of Southampton,

Highfield Campus

Southampton, SO17 1BJ

Phone: +44 (0) 23 8059 5578

1: This study was completed whilst Dr Samantha Broyd was at the School of Psychology, University of Southampton, UK. Her present address is the Centre for Psychophysics, Psychophysiology and Psychopharmacology, School of Psychology, University of Wollongong, Wollongong, NSW, Australia

Abstract

The ability to regulate our emotional responses is crucial to effective functioning in daily life. Whilst there has been extensive study of the brain potentials related to valenced stimuli, the neural basis of the ability to regulate actions elicited by these remains to be clarified. To address this, 40 volunteers undertook an approach-avoidance paradigm. In the congruent condition, participants approached pleasant and avoided unpleasant stimuli. In the incongruent condition, the opposite was the case, requiring the regulation of natural emotional response tendencies. Both behavioural and electrophysiological indices of emotional regulation were recorded. Congruency effects were observed at both the behavioural and electrophysiological level. Reaction times were faster and the LPP larger, when performing emotionally congruous relative to incongruous actions. Moreover, neural and behavioural effects were correlated. The current results suggest that the LPP congruency effect can be considered a neural marker of individual differences in emotion driven action tendencies. We discuss whether this reflects emotion regulation, effort allocation, or correct mapping of stimulus response tendencies.

Keywords: Approach, Avoidance, Emotion Regulation, Event Related Potentials, Late Positive Potential.

Introduction

An organism's safety and survival depends to some extent on the inbuilt tendency to approach positive (i.e. rewarding, safe, pleasant) and avoid negative (i.e. dangerous, threatening, unsafe) stimuli or events. On occasion, however, it is necessary to override these tendencies if we are to act optimally and prosper in daily life. Without this ability to regulate our responses to these emotionally valenced stimuli, we cannot, on the one hand resist temptation, on the other be brave and face dangerous and difficult situations. An inability to do this (i.e. emotional dysregulation) is associated with a number of psychopathologies (Davidson, 1998, 2002; Phillips, Ladouceur, & Drevets, 2008a, 2008b). Despite the importance of this ability, most studies of emotion-related responses focus on the perception and classification of emotional stimuli, rather than the regulation involved in the preparation to complete an appropriate regulated action (Burgdorf & Panksepp, 2006; Calder, Lawrence, & Young, 2001; LeDoux, 2000).

The approach-avoidance (AA) concept and associated methodology has been developed to study the action stage in emotional responding and specifically to uncover how individuals can override their natural tendencies to respond to emotionally charged stimuli (Chen & Bargh, 1999; Solarz, 1960). The AA paradigm involves presenting participants with emotionally valenced stimuli on a computer screen and then requiring them to either "approach" or "avoid". Typically these studies involve a task where participants respond to valenced pictures from the standardized International Affective Picture System (IAPS) set (Lang, Bradley, & Cuthbert, 1999), or a standardized valenced word set (Fazio, Sanbonmatsu, Powell, & Kardes, 1986) by pulling or pushing a lever. More sophisticated tasks have also

been used where either participants control a manikin on the screen which acts as a virtual self that is moved towards or away from stimuli, or simply experience a change in stimulus size which triggers approach or avoidance. In the congruent condition (CC), participants are prompted to perform “natural” pleasant-approach/unpleasant-avoid actions. In the incongruent condition (IC), participants have to over-ride these natural tendencies by approaching unpleasant and avoiding pleasant stimuli. Participants have faster reaction times (RT) when performing congruent than performing incongruent actions. This confirms the automatic predisposition to approach pleasant and avoid unpleasant stimuli, and highlights the additional effort needed to regulate these tendencies when required (Bamford & Ward, 2008; Chen & Bargh, 1999; De Houwer, Crombez, Baeyens, & Hermans, 2001; Duckworth, Bargh, Garcia, & Chaiken, 2002; Krieglmeier, De Houwer, & Deutsch, 2012; Neumann & Strack, 2000; Rotteveel & Phaf, 2004; Solarz, 1960; Wentura, Rothermund, & Bak, 2000). The difference in the speed of the response on congruent compared to the incongruent trials has been termed a congruency effect; for example a large congruency effect would be observed when comparing congruent trials with very fast responses to incongruent trials with very slow responses, whereas more similar response times for congruent and incongruent trials would represent a smaller congruency effect. The size of the congruency effect can therefore be used to index the difficulty individuals experience when asked to over-ride their normal AA response pattern and complete the incongruent action.

Surprisingly little is known about the underlying *neural* basis of emotion-related AA actions. Evidence from electroencephalographic (EEG) studies suggests a frontal asymmetry of approach-avoidance processing, with approach tendencies being lateralized to the left frontal region and avoid to the right (Davidson, Ekman, Saron,

Senulis, & Friesen, 1990; Harmon-Jones & Allen, 1998). However, these studies typically used mood induction procedures to get the participant into a frame of mind ready to approach or avoid, rather than measuring brain potentials whilst *a response* is being prepared and executed and base their analysis on averaged EEG activity over an extended period of time (e.g. 6 minutes) whilst the participants are in these particular moods. Miller & Tomarken (2001) employed EEG in a monetary incentive delay task to look at frontal asymmetry when preparing responses to gain reward (approach) and avoid punishment (avoid), however the task included only congruent responses. Such studies therefore do not allow the examination of specific event-related brain activity associated with the preparatory phase of congruent and incongruent approach-avoidance actions. Further, Miller et al., (2013) argued that we need to go beyond EEG activity related to broad brain areas and asymmetry, and search for specific neural markers of these crucial emotion driven behaviours.

To-date three studies have looked more specifically at these brain processes by examining Event-Related Potentials (ERPs) in AA tasks in healthy volunteers. All three measured neural responses at the P3, which is thought to reflect the allocation of attention toward task-relevant and emotionally salient stimuli (Keil et al., 2002; Polich, 2007), and have produced inconsistent findings. Two of these studies focused on the influence of personality traits on AA responses. van Peer et al., (2007) found differences at the P3 component only in participants who had high scores on the Behavioural Inhibition Scale (Carver & White, 1994), and who had also been given cortisol (as compared to a within subjects placebo condition). These differences manifested as enhanced P3 amplitude to unpleasant (congruent) compared to pleasant (incongruent) trials in the avoid condition. Ernst, Weidner, Ehliis, & Fallgatter (2012) focused on the relation between Behavioural Activation Scale scores (Carver &

White, 1994), P3 amplitudes, and AA behaviours. They found an overall behavioural congruency effect but no corresponding P3 congruency effect. The paper most relevant to our question was authored by Ernst et al., (2013) who investigated AA responses more generally without focus on personality traits. They discovered a congruency effect at the early components, N1 and N2, for positive stimuli (larger amplitudes for approach than avoid) but no congruency effects were seen at the P3 component. Results from these studies therefore are mixed for the P3 component but also indicate that early components such as the N1 and N2 may be involved. Previous literature has shown differentiation at these components between emotional and neutral stimuli (Foti, Hajcak, & Dien, 2009; Keil et al., 2002), with larger amplitudes for emotional stimuli. It is therefore possible that an action-based differentiation could occur in relation to these components too.

Another component that might be especially important in the preparation of regulated actions is the LPP. Whilst the P3 is thought to reflect the allocation of attention toward task-relevant and emotionally salient stimuli (Keil et al., 2002; Polich, 2007), the late positive potential (LPP), extending outside the latency of P3 well beyond 1000 ms, reflects continued emotion stimulus processing. Research investigating the LPP in this context illustrates its sensitivity to emotional content, with larger amplitudes to emotional than neutral stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Hajcak, Dunning, & Foti, 2009; Hajcak, MacNamara, & Olvet, 2010; Hajcak & Olvet, 2008; Schupp et al., 2000; Schupp, Junghöfer, Weike, & Hamm, 2004).

Crucially, the LPP is also found to be sensitive to the active regulation of emotional responses, where a reduction in LPP amplitude is observed following reappraisal (Hajcak & Nieuwenkis, 2006; MacNamara, Foti, & Hajcak, 2009), and

suppression (Moser, Hajcak, Bukay, & Simons, 2006). The P3 and the LPP may index different aspects of emotional processing with the P3 and early LPP sensitive to intrinsic factors (whether the stimuli is emotional or neutral) and the late LPP more sensitive to extrinsic factors (one's interpretation or regulation of that stimuli; MacNamara, Foti, & Hajcak, 2009). Despite all this supporting evidence for its role in emotion regulation no study has focused specifically on this component as a marker for the regulation of emotion based AA actions.

It is important to note that there is some overlap between P3 and LPP components, leading to a lack of clarity between studies given the different temporal definitions of LPP employed (see Weinberg & Hajcak, (2010) for a review of the different time windows). To address this Hajcak, MacNamara, & Ovlet (2010) recommend dividing the P3/LPP in multiple time windows following stimulus presentation. We have adopted this recommendation in the current study.

Our goal in the current study was to examine whether the LPP is a neural marker for the regulation of AA actions to emotional stimuli. In doing so we hoped to specify more precisely the neural underpinnings of congruent (automatic) and incongruent (regulated) actions during AA, and investigate further the functional significance of the LPP. Our predictions are based on the existing emotion regulation literature in the neural and the behavioural domains. On the neural level, LPP amplitudes are smaller for effectively regulated responses (Hajcak & Nieuwenkis, 2006; MacNamara, Foti, & Hajcak, 2009; Moser, Hajcak, Bukay, & Simons, 2006). We would therefore predict that a regulated (incongruent) response would have a comparatively smaller amplitude than an unregulated more automatic (congruent) one and so it follows that the more regulated a response, the larger the difference between the incongruent and congruent amplitudes and the larger the LPP congruency effect.

In contrast, at the behavioural level, an individual who can effectively regulate responses should be able to execute an incongruent response with little additional effort compared to a congruent response leading to similar response times for both conditions producing a small congruency effect.

Our specific predictions were; (i) a congruency effect for the LPP component with a larger LPP for congruent and a smaller LPP for incongruent trials (ii) that this effect would be negatively correlated with a RT congruency effect – a larger LPP congruency effect (suggesting more efficient emotion regulation in the incongruent condition) would be associated with a smaller RT congruency effect. Although our focus is on the LPP our extension across other ERP components allows an investigation of the neural profile of affective automatic (congruent) versus regulated (incongruent) action preparation and ultimately to differentiate the roles of different neural processes occurring during action preparation - mapping the time course of the regulation of emotion-driven actions.

Materials and methods.

Participants

A total of 40 undergraduates (32 female, mean age = 21.72 years, SD = 3.24 years) participated in this experiment for course credits, of which, 34 (27 female, mean age 21.68 = years, SD = 3.41 years) remained in the final analyses. Six participants were excluded due to unusable EEG data (see electrophysiological acquisition and processing section for further details). All had normal or corrected-to-normal vision and none reported neurological problems. All participants were familiarised with the EEG recording procedure and task requirements before informed

consent was taken. All gave informed consent and were debriefed after the experiment. The study protocol was approved by the University of Southampton ethics committee.

AA Task Design

Picture stimuli were taken from the IAPS (Lang, Bradley, & Cuthbert, 1999). There were 80 picture stimuli, 40 pleasant and 40 unpleasant (see appendix for IDs of images used). The pleasant and unpleasant pictures differed significantly on valence $t(78) = 19.28, p < .001$. Pleasant pictures had an average rating of 7.02 (SD 0.70), and unpleasant pictures had an average rating of 3.24 (SD 1.02), on a 1-9 scale where the higher the number the more pleasant the rating, (Lang, Bradley, & Cuthbert, 1999). Average arousal ratings for pleasant and unpleasant pictures were 4.90 (SD 1.31) and 5.17 (SD 1.25) respectively, on a 1-9 scale where the higher the number the higher the arousal rating, (Lang, Bradley, & Cuthbert, 1999), and did not differ significantly between the conditions $t(78) = 0.92, p = .360$. The neutral stimulus was a grey square. All stimuli measured 8 x 8 cm and were presented in a lateralized manner on a computer monitor positioned 80 cm in front of the participant at eye level.

Each trial proceeded as follows: a fixation-cross appeared in the centre of the screen (plain white background). After 500 ms two stimuli appeared at the same time side by side on the screen, a valenced image on one side and a neutral stimulus (a grey square) on the other. Participants made their responses on a two choice button box, which they held in both hands and controlled with the left and right thumbs. The

congruent condition (CC) and incongruent condition (IC) were presented in blocks with different response instructions given to participants for each.

In the CC participants had to approach pleasant and avoid unpleasant stimuli. To do this they were asked to evaluate the valenced image and then press the button on the same side as the valenced image if they “liked it” (*approach action*), but press the other button on the side of the neutral grey square if they “did not like” the valenced image (*avoid action*). They were asked to do this as quickly and as accurately as possible; there was no designated cut off time although slow responses were removed at the analysis stage (see results section). When they responded a response effect reinforced their response; the item on the same side as their response got bigger as if approaching, while the item on the other side retreated as if avoiding (see Figure 1). In the IC the opposite response set was established - participants had to approach unpleasant and avoid pleasant items. To do this they were asked to respond on the same side as the image if they “didn’t like” the image and the opposite side if they did. Once again the item on the same side as their response got bigger on the screen as if approaching, and the item on the opposing side retreated as if avoiding. The images then stayed on screen for 1000 ms. Upon completion of each trial the images were replaced by a plain white background and there was a variable inter-trial interval which ranged between 750 ms and 1500 ms with an average of 1000 ms. In this design both congruent and incongruent trials include responses on the same side as the stimulus (approach) and the opposite side (avoid), meaning that the congruent and incongruent conditions do not differ in terms of spatial matching between stimulus and response polarities ensuring that Simon effects cannot contribute to our results.

Figure 1 - about here.

Procedure

Participants were seated in front of a monitor in the experimental room and fitted with the recording electrodes. Each participant completed two blocks: one CC and one IC. For each block, each pleasant/unpleasant image was presented twice – once on each side in a random order, providing 80 trials for each of the four conditions (i.e. approach pleasant, avoid pleasant, approach unpleasant, avoid unpleasant) giving a total of 160 congruent trials and 160 incongruent trials. Each block took between 5 and 10 minutes to complete. The order of blocks was counterbalanced across participants. Before each block began, participants performed 10 practice trials to ensure that the participants were confident with the instructions.

Electrophysiological acquisition and processing

An electrode cap (Easycap, Herrsching, Germany; See Figure 2 for Montage) containing 66 equidistant spaced silver/silver chloride (Ag/AgCl) electrodes was fitted to each participant's head and EEG was recorded using Neuroscan Synamps² 70 channel EEG system, DC-coupled recording equipment. The data were sampled at 500 Hz with a low pass filter of 70 Hz and referenced to an electrode on the nose. A ground electrode was fitted midway between the electrodes at the vertex and frontal sites. Vertical (vEOG) and horizontal electro-oculogram (hEOG) were recorded using two electrodes placed directly beneath the left and right eyes and affixed with tape, and two electrodes placed above the left and right eyes which were included within the electrode cap. Impedances for vEOG and hEOG, reference and cap electrodes were kept below 5 k Ω . The continuous EEG data were transformed using a DC offset and linear detrend algorithm in neuroscan (Neuroscan 4.4). On each trial ERP data were epoched to the stimulus from 200 ms prior to stimulus onset until 2000 ms post-

stimulus presentation. An ocular artifact reduction procedure (Semlitsch, Anderer, Schuster, & Presslich, 1986) based on left eye vEOG activity was used to remove blink artifacts. Further, any epoch that exceeded $\pm 100 \mu\text{V}$ at any non-frontal scalp site was rejected. The 200 ms pre-stimulus interval was used as baseline and data were filtered 48 dB down at 32 Hz using a low-pass filter. 6 participants were excluded from the analysis due to significant artefacts which led to fewer than 12 trials per condition being available (Moran, Jendrusina, & Moser, 2013). 34 participants remained in the final dataset, all of whom had a minimum of 20 trials in each condition (approach pleasant $M = 51$, $SD = 17$; avoid pleasant $M = 50$, $SD = 18$; approach unpleasant $M = 49$, $SD = 18$; avoid unpleasant $M = 50$, $SD = 17$).

Figure 2 - about here.

Behavioural data pre-processing

Prior to analysis, RT distributions were iteratively trimmed to include scores within three standard deviations of the mean, for each condition and participant. Trials in which participants had made an incorrect response, or did not complete the instructed action for the displayed valence, were removed from both the RT and the ERP analysis.

Electrophysiological data pre-processing

From the grand mean ERP averages, we identified a number of time windows to capture the main components of interest. Based on grand averages and topography LPP was defined as mean amplitude between 350 ms and 930 ms. In order to investigate effects at this component over time we examined the LPP across 3

intervals: LPP1 (350-530 ms), LPP2 (530-730 ms), and LPP3 (730-930 ms), over electrodes (1, 5, 13, 25).

A strong N1 peak also emerged between 160-210 ms. Previous literature has shown differentiation at this component between emotional and neutral stimuli (Foti et al., 2009; Keil et al., 2002), and Ernst et al., (2013) found evidence of a differentiation based on required action here. Therefore, we explored this early component; based on the grand mean ERP averages and topography, we identified the N1 as mean amplitude between 160-210 ms, at electrodes (12, 13, 14, 24, 26, 37, 38, 39, 40).

Data analysis

A repeated measures analysis of variance (ANOVA) was conducted on RT with *Valence* (Pleasant/Unpleasant), and *Response* (Approach/Avoid) as within-subjects factors. The congruency effect appears as a *Valence* by *Response* interaction.

We performed the conceptually identical comparisons for the neural data. We ran a repeated measures ANOVA with *Valence* (Pleasant/Unpleasant), *Response* (Approach/Avoid), *Time* (LPP1, 350-530 ms; LPP2, 530-730 ms; LPP3, 730-930 ms), and *Electrode* (1, 5, 13, 25) as within-subjects factors; for the N1 data we ran a repeated measures ANOVA with *Valence* (Pleasant/Unpleasant), *Response* (Approach/Avoid), and *Electrode* (12, 13, 14, 24, 26, 37, 38, 39, 40) as within-subjects factors.

Results

Reaction Time Data

As predicted there was a significant RT congruency effect reflected in the *Valence* by *Response* interaction, $F(1,33) = 37.33, p < .001 (\eta^2 = .53)$. Participants

were faster to approach ($M = 763$ ms, $SD = 126$ ms) than avoid ($M = 1049$ ms, $SD = 300$ ms) pleasant stimuli, $t(33) = 6.61$, $p < .001$ ($d = 2.30$), and faster to avoid ($M = 812$ ms, $SD = 147$ ms) than approach ($M = 1006$ ms, $SD = 297$ ms) unpleasant stimuli, $t(33) = 5.10$, $p < .001$ ($d = 1.78$). There was also a main effect of *Response*: approach responses were faster overall than avoid responses, $F(1,33) = 18.45$, $p < .001$ ($\eta^2 = .36$) (Approach $M = 884$ ms, $SD = 211$ ms; Avoid $M = 930$ ms, $SD = 223$ ms). However, the main effect of *Valence* was not significant, $F(1,33) = 0.30$, $p = .86$ ($\eta^2 = .001$) (Pleasant $M = 906$ ms, $SD = 213$ ms; Unpleasant $M = 909$ ms, $SD = 222$ ms).

Electrophysiological data

N1

The analysis for the N1 revealed no significant effects for *Valence* $F(1,33) = 0.02$, $p = .89$ ($\eta^2 = 0.00$), *Response* $F(1,33) = 0.61$, $p = .44$ ($\eta^2 = 0.02$), the *Valence* by *Response* interaction $F(1,33) = 0.01$, $p = .92$ ($\eta^2 = 0.00$), and the *Valence* by *Response* by *Electrode* interaction $F(8,264) = 5.71$, $p = .80$ ($\eta^2 = 0.02$).

LPP

For the LPP there was a significant *Valence* by *Response* interaction, $F(1,33) = 4.36$, $p = .045$ ($\eta^2 = 0.12$) (See Figure 3). For pleasant stimuli the amplitude was larger for the approach ($M = 3.73$ μv , $SD = 6.12$ μv) than avoid responses ($M = 1.89$ μv , $SD = 4.93$ μv), $t(33) = 2.16$, $p = .039$ ($d = 0.35$). For unpleasant stimuli the amplitude was numerically larger for the avoid (4.89 μv , $SD = 6.62$ μv) than for the approach responses (3.03 μv , $SD = 4.83$ μv), however this did not reach significance, $t(33) = 1.66$, $p = .11$ ($d = 0.32$). The *Valence* by *Response* by *Electrode* interaction was not significant, $F(3,99) = 1.93$, $p = .13$ ($\eta^2 = 0.06$) showing that the congruency

effect occurred at all electrodes. The main effect of *Valence* was significant, $F(1,33) = 7.68, p = .009, (\eta^2 = 0.19)$, with larger LPP amplitude seen to unpleasant ($M = 3.96\mu\text{v}$, $SD = 4.79\mu\text{v}$) than pleasant stimuli ($M = 2.81\mu\text{v}$, $SD = 4.97\mu\text{v}$). The main effect of *Response* was not significant, $F(1,33) = 0.0, p = .985 (\eta^2 = 0.00)$.

Time course of LPP effects.

There was a main effect of *Time* $F(2,66) = 7.36, p = .001 (\eta^2 = 0.02)$, simply showing that mean amplitudes changed over the 3 time periods (LPP1: $M = 2.87$, $SD = 5.56$; LPP2: $M = 4.64$, $SD = 4.80$; LPP3: $M = 2.66$, $SD = 4.89$).

There was a significant *Valence by Time* interaction $F(2,66) = 4.36, p = .017 (\eta^2 = 0.12)$ showing that the differentiation between unpleasant and pleasant amplitudes was larger at the LPP3 than the other time windows (LPP1: Pleasant $M = 2.49$, $SD = 5.57$, Unpleasant $M = 3.25$, $SD = 5.88$; LPP2: Pleasant $M = 4.21$, $SD = 5.00$, Unpleasant $M = 5.06$, $SD = 4.97$; LPP3 Pleasant $M = 1.74$, $SD = 5.42$, Unpleasant $M = 3.57$, $SD = 4.71$) reflecting perhaps the sustained processing of unpleasant stimuli.

There was also a significant *Response by Time* interaction $F(2,66) = 22.90, p < .001 (\eta^2 = 0.41)$, showing that for the LPP1 and LPP2 time windows approach amplitudes were larger than avoid, (LPP1: Approach $M = 3.20$, $SD = 5.35$, Avoid $M = 2.54$, $SD = 6.00$; LPP2: Approach $M = 4.90$, $SD = 4.66$, Avoid $M = 4.37$, $SD = 5.36$) but the reverse was true at LPP3 (Approach $M = 2.04$, $SD = 5.08$, Avoid $M = 3.27$, $SD = 5.19$)

The *Valence by Response by Time* interaction, $F(2,66) = 1.92, p = .154 (\eta^2 = 0.06)$ did not reach significance, showing that the congruency effect at the LPP occurred at all three time points

Figure 3 - about here

Correlations between neural and behavioural congruency

The RT and the LPP neural congruency effects were calculated by computing a difference score for each so that a positive score means a larger congruency effect. This is achieved in the RT domain by the calculation Incongruent (slower times, larger RT) minus Congruent (faster times, smaller RT) and in the ERP domain by the calculation Congruent (larger amplitude) minus Incongruent (smaller amplitude). These RT and LPP neural congruency effects were positively correlated for the pleasant valence ($r = .45, p = .007$) but did not reach significance for the unpleasant valence ($r = .28, p = .114$). Individuals with large LPP differences between the CC and IC (i.e. a relatively small incongruent amplitude versus a larger congruent amplitude) tended to also have larger RT differences (i.e. a relatively slow incongruent response, and a correspondingly fast congruent response) between the conditions (see Figure 4).

Figure 4 – about here.

We recognized that because responses were faster in the congruent than in the incongruent condition, the time at which the stimulus increased in size would be earlier for congruent than for incongruent trials. Changes in complexity can affect the amplitude of the LPP (Bradley, Hamby, Löw, & Lang, 2007). So in order to rule out the possibility that the change in stimulus size, and corresponding complexity, affected the LPP amplitude in our study, we checked whether the size of the LPP

amplitude correlated with speed of RT in each condition. If the timing of the complexity change affected the LPP, then the LPP amplitude would be correlated with speed of response. However, LPP amplitude did not correlate with the speed of response in any condition: pleasant approach LPP amplitude with pleasant approach RT, $r = .10$, $p = .566$; pleasant avoid LPP amplitude with pleasant avoid RT, $r = .07$, $p = .692$; unpleasant approach LPP amplitude with unpleasant approach RT, $r = -.08$, $p = .659$; unpleasant avoid LPP amplitude with unpleasant avoid amplitude, $r = .16$, $p = .380$, indicating that the earlier change in stimulus size for congruent than incongruent trials did not affect LPP amplitude.

To investigate whether congruency effects are associated with the congruent or incongruent conditions, or both, we ran correlations between the Congruency Effect and the constituent conditions. We found that the LPP the congruency effect was associated with both congruent and incongruent trials. For pleasant stimuli the LPP congruency effect was significantly positively correlated with LPP amplitude in the congruent approach condition $r = .62$, $p < .001$, and negatively associated with the incongruent avoid condition although this did not reach significance $r = -.24$, $p = .177$. For the unpleasant stimuli the LPP congruency effect was significantly positively correlated with the congruent avoid condition $r = .73$, $p < .001$, and significantly negatively correlated with the incongruent approach condition $r = -.35$, $p = .040$. The RT congruency effect was significantly correlated with the incongruent conditions but not the congruent conditions. For the pleasant stimuli the RT congruency effect was significantly correlated with the pleasant approach response times $r = .91$, $p < .001$, but not with pleasant avoid response times $r = .17$, $p = .340$. For the unpleasant stimuli the RT congruency effect was significantly correlated with the unpleasant avoid condition $r = .88$, $p < .001$, but the association with the

unpleasant approach condition did not reach significance $r = .27, p = .125$. Thus the incongruent, more regulated, responses are associated with congruency effects at the LPP, and in the RT domain. Neural effects also appear sensitive to the congruent, more automatic response.

Discussion

Our study is the first to focus on the LPP congruency effect as a neural marker of emotion driven action preparation in an approach-avoidance (AA) paradigm. We found that AA emotion-driven actions may be differentiated at both the behavioural and the neural levels. There are a number of notable findings.

First, consistent with previous literature (Bamford & Ward, 2008; Chen, M and Bargh, 1999; De Houwer et al., 2001; Duckworth et al., 2002; Neumann & Strack, 2000; Rotteveel & Phaf, 2004; Solarz, 1960; Wentura et al., 2000) we see a reaction time (RT) congruency effect: participants are faster to approach than avoid pleasant emotional stimuli, but faster to avoid than approach unpleasant stimuli. This reflects the automatic predisposition to approach pleasant and avoid unpleasant stimuli, and the additional effort required to regulate these tendencies when required.

Second, on the neural level, significant congruency effects were seen at the LPP. Atypical incongruent responses (avoid pleasant/approach unpleasant) have smaller amplitudes than the typical congruent responses (approach pleasant/avoid unpleasant). The LPP congruency effect reached significance for the pleasant stimuli, with a weaker effect for the unpleasant stimuli. The congruency effects at the LPP show that the neural response to identical stimuli is modulated by the required action. Thus the LPP appears to be a neural marker for the preparation of AA *actions* to emotional stimuli. Correlations revealed that both the congruent and incongruent

trials were associated with this effect indicating that individual differences in both the automatic and more regulated response play a vital role in these neural effects.

Further, investigation of the time course of this effect showed that it occurred across an extended period of time (350-930ms) reflecting sustained and ongoing differences based on response preparation.

Third, the RT and the LPP congruency effects were correlated showing that neural effects seen at LPP might be associated with the behavioural effects observed in the RT data. However, this correlation was in the opposite direction to our prediction. We predicted a negative correlation between the LPP and behavioural congruency effects. Following findings from previous emotion regulation literature (Hajcak & Nieuwenkis, 2006; MacNamara, Foti, & Hajcak, 2009; Moser, Hajcak, Bukay, & Simons, 2006) we predicted a regulated response at the LPP would consist of a relatively small LPP amplitude for incongruent responses reflecting efficient emotion regulation. When this is compared to a more automatic larger amplitude for congruent responses we would get a larger LPP congruency effect the more regulated the incongruent response. We predicted that this would be linked to a well regulated response in the behavioural domain which would consist of faster completion of the incongruent action and thus a smaller difference between the incongruent and congruent response times and a smaller RT congruency effect. What we actually observed was that a relatively large incongruent LPP amplitude (compared to the congruent) is correlated with a relatively fast incongruent response (compared to the congruent). And the relatively smaller LPP amplitudes are correlated with relatively slower incongruent responses. This pattern was the same for the congruent trials. Thus the differences between the LPP amplitudes seem to be associated with the

correct mapping of stimulus to task-relevant response but it is not completely clear whether the differences at the LPP reflect emotion regulation.

One persuasive alternative is that the LPP reduction in the incongruent condition reflects the effort needed to override the automatically prepared behaviour and to produce the currently appropriate response. Whilst this seems like a plausible alternative, previous research has shown that it is possible to upregulate (increase) the LPP when asked to and so this cannot be explained in terms of effort as this would result in a smaller LPP not larger if regulating cost effort. (MacNamara et al 2009). Hajcak et al., (2010 review) state that the findings reported by MacNamara show that regulation related changes at the LPP cannot be attributed to cognitive load. In terms of our study, if the reduction in the LPP reflected effort we would expect the amplitude at the LPP to be related to the speed of response, with smaller amplitudes at the LPP being linked to the slowing of responses reflecting this effort. However, from the correlations we see that amplitude is not associated with speed of response at all. Thus it seems that our results cannot entirely be explained in terms of effort either.

Another related suggestion is that the effects might be driven by a Simon effect where responding on the same side as the stimulus is easier than responding on the opposite side. However in this study congruent trials had both same side (approach pleasant) and opposite side (avoid unpleasant) responses, and the same was true for the incongruent trials (same side; approach unpleasant, opposite side; avoid pleasant). In fact congruent responses were consistently associated with larger amplitudes and incongruent with smaller, whereas approach (same side) and avoid (opposite side) responses had no consistent affect on amplitude – for pleasant stimuli same side (approach) had larger amplitudes than opposite side (avoid), but the reverse

was true for the unpleasant stimuli. So Simon effects are ruled out as a possible explanation in this instance.

We have also ruled out the possibility that changes in the stimulus complexity or stimulus offset had an effect on the results. If this were the case then the time at which this occurred would have been earlier for congruent trials than incongruent, and so the time at which this occurred would be associated with the amplitude of the LPP. Correlations show that this is not the case and that speed of response in each condition does not correspond to amplitude at the LPP. Thus the stimulus effects or offset are not associated with the changes we see at the LPP in this study.

From this investigation it is clear that the LPP is a marker for emotion action preparation; this is an important step forward in our understanding of the specific neural markers of these crucial actions. Large differences between the automatic and more regulated conditions at the LPP are associated with large differences between these conditions at the behavioural level and so the LPP reflects individual differences in completion of automatic and more controlled actions. But further research, perhaps involving active instructions to up or down regulate evaluation of valenced stimuli preceding the actions, would be needed to determine the role that effort and regulation might play in these individual changes at the LPP.

Finally in contrast to Ernst et al., (2013) we found no evidence of N1 action effects. Our action effects occurred later in the processing stream during an interval where, in this task, evaluation and action preparation are occurring. There are other differences between our study and the Ernst et al. studies, which are also worth noting. Ernst found a neural congruency effect in the pleasant domain, at the early components N1 and N2, with larger amplitudes to approach pleasant than to avoid pleasant, but no corresponding behavioural effects. The opposite pattern was seen for

the unpleasant stimuli; no neural congruency effects, but a behavioural effect with faster responses to avoid than approach. We did not find any neural congruency effects at the N1 component but demonstrated a strong link between the neural congruency effects at the LPP and the behavioural effects. The two studies may have uncovered complementary findings; that early neural effects (N1, N2) may somehow resolve the later behavioural effects, and later neural effects (LPP) drive or increase them. Further research into the conditions that determine which neural correlates are activated and how they affect later behaviour is needed. A further difference between our task and that of Ernst et al is that we lateralised our stimuli. Because this lateralisation was fully counterbalanced across valence and condition we would not expect this to affect our results, but it is a key difference between the tasks that should be noted, and it would be valuable to replicate our findings across AA paradigms.

A limitation of the current design should be noted for future research. We included a variable delay between trials to prevent jitter, however after baseline correction there were still small differences (but non significant) between conditions as the next trial started, possibly reflecting sustained and ongoing processing of emotional stimuli. These differences did not contribute to any of our findings as for the unpleasant stimuli these were negligible (0.01 μ V) and for the pleasant stimuli these were still small at (0.4 μ V) and in the opposite direction to any of our findings (i.e. congruent more negative than incongruent to begin with) but increasing the temporal length between trials in future may improve the task.

In summary we have demonstrated that the predisposition to approach and avoid shown in the behavioural domain, is linked to, and perhaps driven by, a corresponding differentiation at the LPP. The LPP amplitude is modified based on the required response to the emotional stimulus, with the relative size of the

amplitudes associated with correct mapping of stimulus to task appropriate response. The LPP congruency effects reflect individual differences in the behavioural ability to complete automatic and more regulated actions. Disruptions in the ability to effectively override the natural tendency and choose the alternative but appropriate action has suggested to be a key factor in the manifestation of addiction (Yücel & Lubman, 2009) and in reward related disorders such as Attention-deficit/hyperactivity disorder (Reimherr et al., 2005). Thus our mapping of the neural responses underlying these typical and atypical emotion-driven actions in a healthy population uncovers a neural correlate from which we can further understand these vital emotion based behaviours, and perhaps, in future, their related disorders. Future research should explore in more depth the role that effort and regulation might play in these individual changes at the LPP. In conclusion the LPP component is important not only in regulation of emotion during passive viewing of stimuli but also in the neural processes involved in the preparation of crucial automatic and regulated *emotion driven actions*.

References

- Bamford, S., & Ward, R. (2008). Predispositions to approach and avoid are contextually sensitive and goal dependent. *Emotion Washington Dc*, 8(2), 174–183. Retrieved from <http://dx.doi.org/10.1037/1528-3542.8.2.174>
- Bradley, M. M., Hamby, S., Löw, A., & Lang, P. J. (2007). Brain potentials in perception: picture complexity and emotional arousal. *Psychophysiology*, 44(3), 364–73. doi:10.1111/j.1469-8986.2007.00520.x
- Burgdorf, J., & Panksepp, J. (2006). The neurobiology of positive emotions. *Neuroscience and Biobehavioral Reviews*, 30(2), 173–87. doi:10.1016/j.neubiorev.2005.06.001
- Calder, a J., Lawrence, a D., & Young, a W. (2001). Neuropsychology of fear and loathing. *Nature Reviews. Neuroscience*, 2(5), 352–63. doi:10.1038/35072584
- Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS Scales. *Journal of Personality and Social Psychology*, 67(2), 319–333. doi: 10.1037/0022-3514.67.2.319
- Chen, M and Bargh, J. A. (1999). Immediate Behavioral Predispositions to Approach or Avoid the Stimulus. *Personality and Social Psychology Bulletin*, 25(2), 215–224. doi:10.1177/0146167299025002007
- Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: covariation with autonomic arousal and affective report. *Biological Psychology*, 52(2), 95–111. doi: 10.1016/S0301-0511(99)00044-7
- Davidson, R. J. (1998). Anterior electrophysiological asymmetries, emotion, and depression: Conceptual and methodological conundrums. *Psychophysiology*, 35, 607–614. doi: 10.1017/S0048577298000134
- Davidson, R. J. (2002). Anxiety and affective style: Role of the prefrontal cortex and amygdala. *Biological Psychiatry*, 51, 68–80. doi: 10.1016/S0006-3223(01)01328-2
- Davidson, R. J., Ekman, P., Saron, C. D., Senulis, J. a, & Friesen, W. V. (1990). Approach-withdrawal and cerebral asymmetry: emotional expression and brain physiology. I. *Journal of Personality and Social Psychology*, 58(2), 330–41. doi: 10.1037/0022-3514.58.2.330
- De Houwer, J., Crombez, G., Baeyens, F., & Hermans, D. (2001). On the generality of the affective Simon effect. *Cognition & Emotion*, 15(2), 189–206. doi:10.1080/02699930125883

- Duckworth, K. L., Bargh, J. A., Garcia, M., & Chaiken, S. (2002). The Automatic Evaluation of Novel Stimuli. *Psychological Science*, 13(6), 513–519. doi:10.1111/1467-9280.00490
- Ernst, L. H., Ehlis, A.C., Dresler, T., Tupak, S. V., Weidner, A., & Fallgatter, A. J. (2013). N1 and N2 ERPs reflect the regulation of automatic approach tendencies to positive stimuli. *Neuroscience Research*, 75(3), 239–49. doi:10.1016/j.neures.2012.12.005
- Ernst, L. H., Weidner, A., Ehlis, A.-C., & Fallgatter, A. J. (2012). Controlled attention allocation mediates the relation between goal-oriented pursuit and approach-avoidance reactions to negative stimuli. *Biological Psychology*, 91(2), 312–20. doi:10.1016/j.biopsycho.2012.08.004
- Fazio, R. H., Sanbonmatsu, D. M., Powell, M. C., & Kardes, F. R. (1986). On the automatic activation of attitudes. *Journal of Personality and Social Psychology*, 50(2), 229–38. doi:10.1111/j.1469-8986.2009.00796.x
- Foti, D., Hajcak, G., & Dien, J. (2009). Differentiating neural responses to emotional pictures: Evidence from temporal-spatial PCA. *Psychophysiology*, 46(3), 521–530. doi:10.1111/j.1469-8986.2009.00796.x
- Hajcak, G., Dunning, J. P., & Foti, D. (2009). Motivated and controlled attention to emotion: time-course of the late positive potential. *Clinical Neurophysiology : Official Journal of the International Federation of Clinical Neurophysiology*, 120(3), 505–10. doi:10.1016/j.clinph.2008.11.028
- Hajcak, G., MacNamara, A., & Olvet, D. M. (2010). Event-related potentials, emotion, and emotion regulation: an integrative review. *Developmental Neuropsychology*, 35(2), 129–55. doi:10.1080/87565640903526504
- Hajcak, G., & Nieuwenhuis, S. (2006). Reappraisal modulates the electrocortical response to unpleasant pictures. *Cognitive, Affective, & Behavioral Neuroscience*, 6(4), 291–297. doi:10.3758/CABN.6.4.291
- Hajcak, G., & Olvet, D. M. (2008). The persistence of attention to emotion: brain potentials during and after picture presentation. *Emotion (Washington, D.C.)*, 8(2), 250–5. doi:10.1037/1528-3542.8.2.250
- Harmon-Jones, E., & Allen, J. J. (1998). Anger and frontal brain activity: EEG asymmetry consistent with approach motivation despite negative affective valence. *Journal of Personality and Social Psychology*, 74(5), 1310–6. doi: 10.1037/0022-3514.74.5.1310
- Keil, A., Bradley, M. M., Hauk, O., Rockstroh, B., Elbert, T., & Lang, P. J. (2002). Large-scale neural correlates of affective picture processing. *Psychophysiology*, 39(5), 641–649. doi:10.1111/1469-8986.3950641

- Krieglmeyer, R., De Houwer, J., & Deutsch, R. (2012). On the nature of automatically triggered approach-avoidance behaviour. *Emotion Review*, 5(3), 280-284
- Lang, P. J., Bradley, M. M., & Cuthbert, B.N., (1999) "International affective picture system (IAPS): Digitized photographs, instruction manual and affective ratings." The center for research in psychophysiology, University of Florida
- LeDoux, J. E. (2000). Emotion circuits in the brain. *Annual Review of Neuroscience*, 23, 155–84. doi:10.1146/annurev.neuro.23.1.155
- MacNamara, A., Foti, D., & Hajcak, G. (2009). Tell me about it: Neural activity elicited by emotional pictures and preceding descriptions. *Emotion*, 9(4), 531–543. doi: 10.1037/a0016251
- Miller, A. & Tomarken, A.J. (2001). Task Dependant changes in frontal asymmetry: effects of incentive cues, outcome expectancies, and motor responses. *Psychophysiology*, 38, 500-511.
- Miller, G.A., Crocker, L.D., Spielberg, J.M., Infantolino, Z.P., & Heller, W. (2013). Issues in localization of brain function: The case of lateralized frontal cortex in cognition, emotion, and psychopathology. *Frontiers in Integrative Neuroscience*, 7, 2. doi: 10.3389/fnint.2013.00002
- Moran, T. P., Jendrusina, A. a, & Moser, J. S. (2013). The psychometric properties of the late positive potential during emotion processing and regulation. *Brain Research*, 1516, 66–75. doi:10.1016/j.brainres.2013.04.018
- Moser, J. S., Hajcak, G., Bukay, E., & Simons, R. F. (2006). Intentional modulation of emotional responding to unpleasant pictures: an ERP study. *Psychophysiology*, 43(3), 292–6. doi:10.1111/j.1469-8986.2006.00402.x
- Neumann, R., & Strack, F. (2000). Approach and avoidance: The influence of proprioceptive and exteroceptive cues on encoding of affective information. *Journal of Personality and Social Psychology*, 79(1), 39–48. doi:10.1037/0022-3514.79.1.39
- Phillips, M. L., Ladouceur, C. D., & Drevets, W. C. (2008a). A neural model of voluntary and automatic emotion regulation: implications for understanding the pathophysiology and neurodevelopment of bipolar disorder. *Molecular Psychiatry*, 13(9), 829, 833–57. doi:10.1038/mp.2008.65
- Phillips, M. L., Ladouceur, C. D., & Drevets, W. C. (2008b). Neural systems underlying voluntary and automatic emotion regulation: toward a neural model of bipolar disorder. *Molecular Psychiatry*, 13(9), 829–829. doi:10.1038/mp.2008.82
- Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology : Official Journal of the International Federation of Clinical Neurophysiology*, 118(10), 2128–48. doi:10.1016/j.clinph.2007.04.019

- Reimherr, F. W., Marchant, B. K., Strong, R. E., Hedges, D. W., Adler, L., Spencer, T. J., Soni, P. (2005). Emotional dysregulation in adult ADHD and response to atomoxetine. *Biological Psychiatry*, 58(2), 125–31. doi:10.1016/j.biopsych.2005.04.040
- Rotteveel, M., & Phaf, R. H. (2004). Automatic affective evaluation does not automatically predispose for arm flexion and extension. *Emotion (Washington, D.C.)*, 4(2), 156–72. doi:10.1037/1528-3542.4.2.156
- Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Cacioppo, J. T., Ito, T., & Lang, P. J. (2000). *Affective picture processing: the late positive potential is modulated by motivational relevance*. *Psychophysiology* (Vol. 37, pp. 257–261). doi:10.1016/S0079-6123(06)56002-9
- Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2004). The selective processing of briefly presented affective pictures: an ERP analysis. *Psychophysiology*, 41(3), 441–9. doi:10.1111/j.1469-8986.2004.00174.x
- Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A Solution for Reliable and Valid Reduction of Ocular Artifacts, Applied to the P300 ERP. *Psychophysiology*, 23(6), 695–703. doi:10.1111/j.1469-8986.1986.tb00696.x
- Solarz, A. K. (1960). Latency of instrumental responses as a function of compatibility with the meaning of eliciting verbal signs. *Journal of Experimental Psychology*, 59(4), 239–245. doi:10.1037/h0047274
- Van Peer, J. M., Roelofs, K., Rotteveel, M., van Dijk, J. G., Spinhoven, P., & Ridderinkhof, K. R. (2007). The effects of cortisol administration on approach-avoidance behavior: an event-related potential study. *Biological Psychology*, 76(3), 135–46. doi:10.1016/j.biopsycho.2007.07.003
- Weinberg, A., & Hajcak, G. (2010). Beyond good and evil: The time-course of neural activity elicited by specific picture content. *Emotion*, 10(6), 767–782. doi:10.1037/a0020242
- Wentura, D., Rothermund, K., & Bak, P. (2000). Automatic vigilance: The attention-grabbing power of approach- and avoidance-related social information. *Journal of Personality and Social Psychology*, 78(6), 1024–1037. doi:10.1037/0022-3514.78.6.1024
- Yücel, D., & Lubman, D. I. (2009). Neurocognitive and neuroimaging evidence of behavioural dysregulation in human drug addiction: implications for diagnosis, treatment and prevention. doi:abs/10.1080/09595230601036978

Figure legends

Figure 1. The sequence of events in each trial.

Figure 2. Montage of the EEG cap.

Figure 3. ERP waveforms for approach and avoidance for pleasant images (left side) and unpleasant images (right side) at a representative electrode site – electrode 13.

Topographical map of the LPP is included.

Figure 4. Valence by Response interaction at the LPP (upper left panel, Means represent average activity across all 4 electrode sites, 1,5,13,25) and for Reaction Times (upper right panel). Lower panel denotes correlations between the congruency effect at the LPP (difference score in μV) and the congruency effect at the behavioural level (difference score in ms).

Appendix

Numbers of the pleasant pictures used were: 1540, 1560, 1640, 1650, 1710, 1910, 1920, 2070, 2080, 2170, 2370, 2501, 2530, 2620, 4100, 4660, 4680, 5020, 5250, 5660, 5750, 5870, 7230, 7260, 7270, 7280, 7320, 7340, 7550, 7570, 8030, 8040, 8050, 8080, 8130, 8161, 8185, 8370, 8490, 8501.

Numbers of the unpleasant pictures used were: 1230, 1270, 2190, 2200, 2230, 2520, 2690, 2700, 2800, 2810, 3000, 3130, 3150, 3170, 3250, 5940, 5970, 6020, 6940, 8010, 8230, 8480, 9000, 9010, 9040, 9041, 9042, 9050, 9080, 9090, 9110, 9190, 9290, 9300, 9360, 9400, 9410, 9500, 9630, 9810

Disclosure Statement

In the last 24 months Professor Sonuga-Barke has received speaker fees from Janssen Cilag, Shire, Medice and QBtech and consultancy, grant funding, advisory board fees and conference support from Shire. All other authors report no conflicts of interest.