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Running Head: Brain Potentials and Consumer Preferences

Neural signals of selective attention are modulated by subjective preferences and buying decisions in a virtual shopping task.

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Abstract

We investigated whether well-known neural markers of selective attention to motivationally-relevant stimuli were modulated by variations in subjective preference towards consumer goods in a virtual shopping task. Specifically, participants viewed and rated pictures of various goods on the extent to which they wanted each item. Afterwards, participants had the opportunity to virtually purchase each item. Using the event-related potentials (ERP) method, we found that variations in subjective preferences for consumer goods strongly modulated positive slow waves (PSW) from 800 to 3000 milliseconds after stimulus onset. We also found that subjective preferences modulated the N200 and the late positive potential (LPP). In addition, we found that both PSW and LPP were modulated by subsequent buying decisions. Overall, these findings show that well-known brain event-related potentials reflecting selective attention processes can reliably index preferences to consumer goods in a shopping environment. Based on a large body of previous research, we suggest that early ERPs (e.g. the N200) to consumer goods could be indicative of preferences driven by unconditional and automatic processes, whereas later ERPs such as the LPP and the PSW could reflect preferences built upon more elaborative and conscious cognitive processes.

Neural signals of selective attention are modulated by subjective preferences and buying decisions in a virtual shopping task

Recent evidence has shown that brain activity measured with the brain event-related potentials (ERP) method co-varies with preferences for consumer goods (Junghöfer et al., 2010; Pozharliev, Verbeke, Van Strien, & Bagozzi, 2015; Schaefer, Buratto, Goto, & Brotherhood, 2016; Telpaz, Webb, & Levy, 2015). This is an important development in an emerging field - consumer neuroscience - that aims to investigate consumer behaviour (CB) with neuroscience methods. The results from two of these studies (Telpaz et al., 2015; Junghofer et al., 2010) suggest that early brain potentials (neural signals occurring less than 300 ms after participants first see the image of a consumer good) can index consumer preferences. These results can be interpreted from the perspective of the "motivated attention" theoretical framework (Lang, Bradley, & Cuthbert, 1997; Schupp, Flaisch et al., 2006), which contends that similar early ERPs reflect automatic attentional processes towards motivationally relevant stimuli (Schupp, Flaisch et al, 2006; Olofsson et al, 2008; Walker et al., 2011). However, a striking aspect of ERP studies of CB is that they do not report consistent links between consumer preferences and late ERP positivities, which are often modulated by motivationally relevant stimuli (Olofsson et al, 2008), and are thought to reflect post-perceptive and controlled selective attention processes (Schupp, Flaisch, Stockburger, & Junghöfer, 2006). In order to investigate this issue, the primary goal of this study was to examine the ERP correlates of consumer preferences with a particular focus on late ERP positivities.

To achieve this goal, we targeted brain potentials known to index distinct subprocesses of motivated attention. More specifically, motivated attention is classically separated in two subprocesses: A quick, “preattentive” mechanism of attentional orientation; and a more overt and controlled form of attention (LeDoux, 1996; Vuilleumier & Huang, 2009). This theoretical approach is based on the notion that, from a neurobiological perspective, attention is seen as the enhancement of neural activity in sensory cortices (Vuilleumier & Huang, 2009), and that the modulation of these processes by affective-motivational factors can occur through two different routes. First a "quick" route would involve subcortical structures predominantly involved in the evaluation of motivational relevance (e.g. the amygdala; Pessoa & Adolphs, 2010; Schaefer et al., 2006). These structures would detect the presence of motivationally relevant information in the environment through sensory inputs and would subsequently modulate activity in sensory cortices through relatively direct pathways (Vuilleumier & Huang, 2009). This route is classically thought to be automatic (Vuilleumier, Armony, Driver, & Dolan, 2001). However, evidence suggests that this route can be modulated by top-down controlled processes (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Pessoa, Padmala, & Morland, 2005).

The second pathway of motivated attention is one in which neocortical networks (mainly frontal and parietal areas) receive inputs conveying emotional information, and subsequently modulate sensory cortices. This mechanism is thought to be linked to overt attentional processes, accompanied by feelings of conscious perception, and they are thought to be more under the control of voluntary processes (LeDoux, 1996; Vuilleumier &

Huang, 2009). Beyond the main theoretical distinction between a quick “preattentive” and a slower overt attentional response, a third process is often proposed in which attentional resources would be allocated to motivationally-relevant stimuli in a temporally sustained manner. This third subtype of motivated attention would most likely involve working memory (WM) processes and facilitate a more elaborative processing of motivationally-relevant information (Schupp, Flaischet al., 2006; Watts, Buratto, Brotherhood, Barnacle, & Schaefer, 2014).

ERP researchers have identified three types of brain potentials to emotional pictures that map onto the three types of attentional processes described above. As some of us explained in previous articles (Walker, O’Connor, & Schaefer, 2011; Watts et al., 2014), ERPs to stimuli of higher motivational relevance (e.g. emotional stimuli, faces, affective stimuli) can be divided into three subtypes. First, pre-400 ms ERPs to motivationally relevant stimuli are thought to reflect a rapid and automatic orientation of attention triggered by evolutionary and/or motivationally relevant properties of external stimuli (Mavratzakis, Herbert, & Walla, 2016; Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp, Flaisch et al., 2006). Second, an ERP called “Late positive potential” has often been observed after 400 ms following the onset of a motivationally relevant stimulus. This ERP is characterised by a strong positivity that can be observed across the entire scalp with maxima in posterior scalp sites (Codispoti, Ferrari, & Bradley, 2007; Schupp et al., 2000). The latencies of this effect vary across studies but they tend to be predominant between 400 and 800 ms (Codispoti, De Cesarei, & Ferrari, 2012). The LPP is thought to reflect overt, post-perceptive attentional responses to motivationally-relevant stimuli that are more sustained in time and for which the involvement of controlled processes would be more important than the pre-400 ms effects (Codispoti et al., 2007; Schupp, Flaisch et al., 2006; Walker et al., 2011). Third, a more sustained ERP positivity for motivationally relevant pictures has been observed after 800 ms post-stimulus onset. This effect consists of a sustained waveform that can last a few seconds after stimulus onset (Diedrich, Naumann, Maier, & Becker, 1997; Foti & Hajcak, 2008; Hajcak & Nieuwenhuis, 2006; Hajcak & Olvet, 2008). The topography of this effect is often widely distributed across the scalp over both fronto-central and centro-parietal sites (Foti & Hajcak, 2008; Hajcak & Olvet, 2008). These ERP effects are commonly labeled as positive slow waves (PSW) (Schupp, Flaisch et al., 2006) or as "late LPP" (Leutgeb, Schäfer, & Schienle, 2009; Schienle, Köchel, & Leutgeb, 2011), and they are thought to reflect sustained attentional processes related to the maintenance and potential manipulation of information in working memory (Schupp, Flaisch et al., 2006).

The vast majority of studies supporting this body of ERP results have used stimuli conveying an intrinsic emotional and evolutionary meaning, such as pictures of faces displaying emotional expressions or pictures of emotional scenes (e.g. dead bodies, scenes of violence and threat, etc.). It is not yet well established if these results can be generalized to objects that have acquired their motivational relevance because of their economic value (i.e. the potential benefits that can be brought by obtaining them), such as consumer goods. There has been a recent surge of studies using neuroimaging (Karmarkar, Shiv, & Knutson, 2014; Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007; Plassmann, O'Doherty, & Rangel, 2007; Smidts et al., 2014; Tusche, Bode, & Haynes, 2010) and psychophysiological methods (e.g. Rasch, Louviere, & Teichert, 2015; Walla, Brenner, & Koller, 2011) to investigate consumer behaviour. However, only a very limited number of studies have approached this question using the ERP method. Previous studies that have examined ERPs related to preferences for consumer goods have focused mainly on early (pre-400) ERPs. For instance, Telpaz et al. (2015) found a relationship between the N200 component and product preferences measured by a behavioural choice procedure in which participants needed to choose between pairs of products. Telpaz et al. (2015) suggested that this N200 effect could reflect an effect of the Feedback-Related Negativity (FRN), an ERP component that overlaps with the N200, and which has been linked to the evaluation of prediction errors in decision-making tasks (Mushtaq, Wilkie, Mon-Williams, & Schaefer, 2016), and more recently, to positive surprise and buying preferences in a virtual shopping task (Schaefer et al., 2016). Furthermore, a study using magnetoencephalography (MEG) found that early brain potentials (between 110 and 230 ms post-stimulus onset) reflecting motivated attention were related to gender-specific preferences for consumer goods (Junghöfer et al., 2010).

Although these studies provide evidence in favour of the notion of the involvement of early attentional responses in consumer preferences, evidence regarding later effects is scant and contradictory. Pozharliev et al.'s (2015) study reported a relationship between the LPP and preferences for luxury goods only when participants were in a social context, and Bosshard et al. (2016), although not using pictures of consumer goods, found a relationship between the LPP and the extent to which brand names were liked. In contrast to these studies, the work by Telpaz et al. (2015) described above did not find effects in the LPP or in any later time window. In addition, to our knowledge no study has reported testing the relationship between the PSW and preferences for consumer goods in a realistic shopping environment. Furthermore, the apparent contradiction between Telpaz et al. (2015) and Pozharliev et al. (2015) regarding late positivities is difficult to resolve as they used markedly different methods: First, Telpaz et al. (2015) repeated the presentation of every individual stimulus 50 times whereas Pozharliev et al. (2015) used single presentations for each item, which may have caused differences between these studies regarding potential habituation effects of late positivities (Ravden & Polich, 1998) ; Second, Telpaz et al. (2015) used procedures in which participants could purchase the viewed products, whereas Pozharliev et al. (2015) did not, which may have caused differences regarding the motivational value of perceiving consumer goods; Third, Telpaz et al. (2015) used a variety of consumer goods, whereas Pozharliev focused on luxury vs. non-luxury items.

Therefore, the primary goal of this study was to examine and characterize the electrophysiological responses to consumer goods that are preferred compared to less preferred goods using a wide diversity of non-repeated consumer goods and a procedure that maximized motivational engagement. In order to fill an important gap in the literature, we focused on the positive slow waves (PSW) and the LPP, but we also tested the effects of consumer preference on the amplitude of the N200 brain potentials in order to provide a comparison with previous research. In order to attain this goal, we asked participants to take part in a modified version of a shopping task used in previous studies (Knutson et al., 2007; Plassmann et al., 2007; Schaefer et al., 2016). In this task, participants were shown pictures of familiar consumer goods, which they could later purchase, and were asked to rate their level of preference towards each item while their scalp EEG was recorded.

A secondary goal of this study was to verify if the same ERPs that are modulated by preference ratings can also vary according to subsequent "purchasing" decisions, and whether any potential relationship between ERPs and subsequent decisions can be accounted for by an effect of preference. Therefore, we also categorized ERPs time-locked to the viewing of consumer goods relative to whether participants decided to buy them or not. Next, we tested if this Buy/No-Buy (BNB) effect on ERPs was still present when only products from a homogenous level of subjective preference were considered, which would attenuate any effect of subjective preference. If any potential effect of BNB were still observed in such circumstances, this could tentatively indicate that the effect of BNB decisions on ERPs can be dissociated from effects of subjective preferences.

Methods

Participants

Forty-five right-handed adults (24 females; mean age=21.64, *SD*=2.77) with no history of neurological or psychiatric disorders participated in this experiment. From this initial sample, seven participants were excluded because they did not have at least 16 artifact-free trials in at least one of the three main conditions ("Low", "Middle", or "High" preference: LP, MP, HP). This criterion was used to make sure that all ERP waveforms had an acceptable signal to noise ratio (Luck, 2005). The final sample had 38 participants (22 females, mean age = 21.49, *SD* = 2.76). Participants were recruited from the student population of a foreign campus of an Australian University (Monash University) located in the greater Kuala Lumpur metropolitan area in Malaysia. They were all fluent in English and had all lived in Malaysia for more than a year. The Ethics committee of Monash University approved the study and all participants signed an informed consent before taking part in the experiment.

Stimuli

We used colour digital pictures of 180 products selected from local shops and online retailers which were familiar to our participants. The average familiarity score reported by this study's participants for the products was 6.51, SD = 1.13, out of a scale ranging from 1 to 9. It should be noted, that this score was significantly higher than the midpoint of the scale (5), t=8.25, p<.001 (two-tailed). We also verified that the means of the familiarity ratings were higher than 5 separately for the three main conditions of the experiment: LP (M=5.77, SD=1.72, t=2.75, p=.009), MP (M=6.61, SD=1.02, t=9.77, p<.001), and HP (M=7.75, SD=0.68, t=25.03, p<.001). These results indicate that the products used in this study were overall familiar to our participants. The products included a large variety of items, such as electronics, food, drinks, sports equipment, and others. We provide examples of our digital pictures in the supplementary section (Supplementary Figure 1). The mean prices of the products, calculated as the mean of the prices of each product in two different retailers, ranged from 2.35 to 66 Malaysian Ringgits (RM, M=24.59, SD=17.59) (based on the conversion rate at the time of data collection, in US dollars, this ranged from 0.56 to 15.84 USD).

Behavioural Paradigm

Participants sat in a comfortable chair at approximately 80 cm from a 22" monitor on which the stimuli were displayed. E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) was used to display the stimuli on the screen. We recorded participants' scalp EEG while they performed a virtual shopping task during which each participant was shown a sequence of 180 products on the screen. For each product, the trial sequence included nine stages (depicted in Figure 1): First, participants saw a fixation (black cross on white screen) displayed for a random duration (800 to 1700 ms). Second, the image of a product was shown on the computer screen for 3 seconds. In stages #3, #4 and #5, they were asked on 9-point Likert scales how pleasant the product was, how much they wanted the product, and how familiar they were with the product. In the sixth stage, a fixation was again displayed for a random duration (800 to 1700 ms). In the seventh stage, the image of the product was shown again with a price superimposed on it. In stage #8, participants saw a fixation again for 1 second. Finally (stage #9), the price superimposed on the image was shown again, and participants were prompted to decide whether or not to buy the product at the offered price from a virtual allocation of RM100 (24 USD), which was reset for every product (see Figure 1). At the end of the experiment, a computer program randomly selected one of the products that were "bought" by the participant. This chosen product and "cash savings", (the RM100 allocation minus the offered price for the product) were given to participants later. This approach was used to make the virtual shopping experience more realistic (see Knutson et al., 2007; Schaefer et al., 2016).

Insert Figure 1 about here

In order to encourage participants to purchase products during the experiment, offered prices were discounted from the means of the prices by 25%. Thus, prices shown to participants ranged between RM1.76 (0.42 USD) and RM49.5 (11.88 USD) (M=18.44, SD=13.19). Furthermore, we sought to minimize possible biases that could be caused by strategies based on buying a minimal amount of products. To achieve this goal, and following previous research (Schaefer et al, 2016), participants lost money on their final cash savings if they did not buy a minimum number of products, according to a schedule previously explained to them. If the number of bought products were less than or equal to 18, RM30 (7.2 USD) would be deducted from the savings. If this number was between 19 and 24, RM15 (3.6 USD) would be lost. If the number was between 25 and 30, participants would lose RM3 (0.72 USD) from their savings. If participants bought more than 30 products, they would not lose any money at the end. All of the aspects of the behavioural paradigm were explained to participants before the experiment, and their understanding was confirmed by a small quiz. The experiment lasted approximately 2 hours.

Electrophysiological data recording and pre-processing

Each participant's scalp EEG was recorded using 32 Ag/AgCl electrodes embedded in "Waveguard" purpose-made caps following the standard 10-20 system of electrode locations and an "ASALAB" amplifier (both manufactured by ANT Neuro, Enschede, Netherlands) at a sampling rate of 512Hz (DC-138 Hz bandwidth). Impedance was kept below 10kΩ, and a common average reference was used during recording. EEG preprocessing followed a standard procedure used in our previous work (e.g., Mushtaq et al., 2016; Schaefer, Pottage, & Rickart, 2011; Watts et al., 2014), using the ERP module of BESA (Version 6.0, BESA GmbH, Gräfelfing, Germany). Data were converted off-line to an average mastoids reference, filtered (0.01-40Hz), segmented into epochs between 200 ms before and 3000 ms after the onset of the product images on the screen (stage #2 of the procedure described above) and baseline corrected. Eye movements were corrected using a multiple source analysis method (Berg & Scherg, 1994; Ille, Berg, & Scherg, 2002) as implemented in BESA ("Surrogate method"). In addition, for each channel, epochs with a difference between the maximum and minimum voltage amplitude > 120 μV and a maximum difference between two adjacent voltage points > 75 μV were rejected (after eye movement artifact correction).

Three ERP waveforms were created based on each individual participant's ratings on the "wanting" scale. For each participant, products rated as 1, 2, or 3 on the wanting scale were categorized as Low Preference (LP), those rated as 4, 5, or 6 as Middle Preference (MP), and those rated as 7, 8, 9 as High Preference (HP). All 38 participants had equal to or more than 16 artifact-free trials in all these three conditions and thus were included for the analyses. The mean numbers of artifact-free trials for LP, MP, and HP were 63, 52.68, and 38.87, respectively. In order to examine whether ERP waveforms can be differentiated by participants' subsequent decisions to buy or not to buy the products, we also created ERP waveforms time-locked to the viewing of the products (stage #2) and separated according to whether they were followed by a "buy" or "no-buy" decision. In addition, we also examined if this Buy vs. No-Buy (BNB) effect could be observed when levels of subjective preference were kept homogenous. To do that, we performed subsample analysis on a group of participants who had enough artifact-free trials to test the BNB effect when only MP trials were considered (N=26). The same effect could not be reliably tested for LP or HP because in these conditions, the numbers of "Buy" or "No-Buy" responses (respectively) were too low, given that participants tended to buy preferred items and decline to buy items with low levels of preference, as expected. To maximize the subsample group size, we used a liberal criterion of a minimum of 12 artifact-free trials for each specific condition, in accordance with previous literature investigating late positive ERP activities (Kim, Vallesi, Picton, & Tulving, 2009; Otten, Quayle, Akram, Ditewig, & Rugg, 2006; Padovani, Koenig, Brandeis, & Perrig, 2011; Watts et al., 2014; Yick, Buratto, & Schaefer, 2015).

ERP quantification

Our analysis of ERP data had two primary goals. First, we wanted to test if previous results about the relationship between the N200 component and consumer preferences could be replicated. Second, we wanted to examine if sustained post-400 positivities (LPP and PSW) were also related to subjective preferences and choice.

Replication attempt of N200 results.

The N200 was quantified using peak to peak scores, as this is often a recommended method to quantify overlapping components such as the P200/N200 complex (Hajcak, Moser, Holroyd, & Simons, 2006; Luck, 2005; Mushtaq, Stoet, Bland, & Schaefer, 2013; Osinsky, Mussel, & Hewig, 2012). Given that the P200 is often linked to the N200 in the same complex, we also analyzed the P200 with peak to peak scores. On the basis of a visual inspection of our waveforms and previous literature (e.g., Telpaz et al., 2015; Walker et al., 2011), we extracted peak amplitudes of each participant from three time windows: 70-150 ms (N100), 130-250 ms (P200), and 200-400 ms (N200). Then, we subtracted N100 from P200 absolute peak amplitudes in order to quantify a peak to peak P200 amplitude. Similarly, we subtracted P200 from N200 absolute peak amplitudes in order to quantify peak to peak N200 amplitudes. In order to perform statistical analyses, we extracted these peak to peak scores from a sample of nine electrodes allowing coverage of Frontal, Central and Parietal sites, in left, midline and right hemispheres: F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4. For both P200 and N200 we then conducted a 3 (Item Category: LP vs. MP vs. HP) x 3 (Anterior-Posterior [AP]: Frontal vs. Central vs. Parietal) x 3 (Laterality [LAT]: Left, Midline vs. Right) repeated-measure analysis of variance (ANOVA). Furthermore, we also conducted a 2 (Buy vs. No-Buy [BNB]) x 3 (AP) x 3 (LAT) repeated-measure ANOVA with the main sample in order to examine the effects of subsequent buying decisions on our ERP waveforms. Next, we performed a 2 (MP/Buy vs. MP/No-Buy) x 3 (AP) x 3 (LAT) ANOVA with a subsample, as explained in the "Electrophysiological data recording and pre-processing" section. Greenhouse-Geisser corrections were applied when necessary, and results were considered significant at $p < .05$. Analyses of the P200 data did not reveal any significant effects and therefore we do not report these further.

Late positivities.

The LPP is usually quantified between 400 and 800 ms, whereas the PSW is usually observed after 800 ms, and can extend to 3 secs or beyond (Diedrich et al., 1997; Foti & Hajcak, 2008; Hajcak & Olvet, 2008). Therefore, we separated the late positive ERPs into 4 consecutive 400-ms windows: 400-800, 800-1200, 1200-1600, 1600-2000, and in accordance with previous research (Foti & Hajcak, 2008; Hajcak & Olvet, 2008), we also quantified a longer time window from 2000 ms to 3000 ms. For each time window, we extracted mean amplitudes that were used in subsequent data analyses and we conducted ANOVAs identical to the ones employed for the N200 data, using the same array of electrodes. These ANOVAs were conducted separately by each time window, and Greenhouse-Geisser corrections were applied when necessary. Given that testing each effect repeatedly across five different time windows could inflate the false positive rate, we corrected the p-value of each effect with the Bonferroni method.

Results

Behavioural data

Manipulation Checks.

We first analyzed how items in LP, MP, and HP categories were perceived by the main sample (n = 38) on the scales of wanting, pleasantness, and familiarity with repeated-measure ANOVAs. Since these categories were derived from the wanting scores, not surprisingly, we found that HP items were wanted more (M = 7.71, SD = 0.32) than MP items (M = 4.98, SD = 0.21, $p < .001$) and LP items (M = 2.07, SD = 0.47, $p < .001$). MP items were also wanted more than LP items ($p < .001$), and these comparisons were accompanied by a very significant main effect of item category on wanting scores, $F(1.41, 52.07) = 2035.59$, $p < .001$, $\eta_p^2 = .98$. As expected, HP items were also perceived to be more pleasant ($M = 7.59$, $SD = 0.67$) than MP ($M = 6.11$, $SD = 0.85$, $p < .001$) and LP items ($M = 4.70$, $SD = 1.22$, $p < .001$), and MP items were perceived to be more pleasant than LP ($p < .001$), and these comparisons were supported by a main effect of category on pleasantness scores, $F(1.28, 47.38) = 168.96$, $p < .001$, $\eta_p^2 = .82$. We also found that HP items were perceived to be more familiar ($M = 7.75$, $SD = 0.68$) than MP ($M = 6.61$, $SD = 1.02$, $p < .001$) and LP items ($M = 5.77$, $SD = 1.72$, $p < .001$), and MP items were more familiar than LP items ($p < .001$), and these contrasts were obtained alongside a significant main effect of category on familiarity scores, $F(1.24, 46.00) = 58.19$, $p < .001$, $\eta_p^2 = .61$.

Next, we wanted to verify if the three categories of subjective preference could truly be accounted by differences in “Wanting” rather than pleasantness, familiarity, or offered price. To address this question, we adopted a multilevel approach to our data. In this analysis, a categorical variable reflecting the 3 preference categories (“Item Category”: LP, MP and HP) was the dependent variable, and scores of wanting, familiarity, pleasantness, and offered prices were the predictors. We hypothesized that if the relationship between wanting scores and item categories disappeared or was significantly reduced after the inclusion of the other predictors, then this result could suggest that the item categories were accounted for by variables other than “wanting”. Using a multilevel approach enabled us to examine these effects at the level of individual trials while taking into account potential between-subjects variability.

Specifically, we used the "linear mixed models" option of SPSS to analyze trial-specific data, while taking into account differences between participants. We included item category (LP = 1, MP = 2, HP = 3) as a dependent variable and first tested the effects of wanting scores on this variable, using an unstructured covariance type. Not surprisingly, the results indicated that wanting scores significantly predicted the preference category ($b = .313$, $p<.001$). Next, we added pleasantness, familiarity scores and offered price to the model. The effect of wanting score slightly increased ($b = .320$, $p<.001$), and it turned out that pleasantness also predicted item category, although the effect size was much smaller ($b = -.010$, $p=.018$) than the effect of wanting. Familiarity ($b = -.003$, $p=.100$) and offered price ($b = -.000$, $p=.827$) did not predict preference category. Consistent with our expectations, these results suggest very strongly that item categories of LP, MP and HP are mainly determined by the "wanting" scores, and that they cannot be fully accounted by pleasantness, familiarity, or offered price. Pleasantness seems to have a statistically significant effect on item category, although with a much smaller effect size than wanting.

Finally, we examined whether there were any thematic biases in the categorization of products into HP, MP and LP. For instance, if electronic products were more frequently categorized into HP than household items (whereas the same imbalance would not be observed in LP and MP), then any comparisons between HP and MP or LP could be compromised by a confound between preference and perceptual differences between groups of products (e.g. electronics products vs. other types of products). The 180 products used in our study can be categorized into 9 product categories: drink, electronic goods , food, health care, home goods, housekeeping goods, kitchen appliance, sports equipment, and stationary. Chi-square tests revealed that none of these product categories were over- or underrepresented in LP (X2 (8) = 7.70, p = .46), MP (X2 (8) = 1.49, p = .99), or HP (X2 (8) = 4.93, p = .76). These analyses indicate that thematic contents of product images were equally distributed within each of the preference categories (HP, MP, LP).

***Buying rate*.**

Next, we examined whether participants' decisions to buy products differed across the item categories. For this analysis, the main dependent variable was a ratio between the number of "Buy" decisions in an item category divided by the total number of items in that particular category. As expected, a repeated-measure ANOVA revealed that participants made buy decisions more often for HP items (M = 0.76, SD = 0.16) than for MP items (M = 0.32, SD = 0.18, p < .001) and LP items (M = 0.05, SD = 0.06, p < .001). The MP-LP contrast was also significant (p < .001), and these contrasts were supported by a significant main effect $F(1.98, 73.07) = 346.25$, $p < .001$, $\eta_p^2 = .90$. As expected, this result confirms that highly preferred items were more likely to be bought during the shopping task.

Brain Potentials

Figure 2 shows a very clear differentiation between highly preferred items compared to less preferred items. Waveforms related to HP items yielded a stronger positivity than both MP and LP starting at approximately 350 ms and this effect appears to be sustained until the end of the epoch. However, the difference between HP and MP seems to progressively diminish after 1200 ms, whereas the HP-LP difference remains robust across most of the epoch. Scalp maps in Figure 2 also show that, at least for the HP-LP contrasts, the topography of the effects encompasses both fronto-central and centro-parietal sites. Figure 3 also shows that the BNB effects are very similar to the effects of subjective preference. In addition, Figure 4 shows a clear effect of subjective preference on the N200 component, indicating that more preferred items are associated to less negative amplitudes than items with lower levels of preference. Statistical analyses described below generally support these observations.

Insert Figures 2, 3 and 4 about here

Subjective preferences

N200.

Analyses on N200 peak to peak scores successfully replicated previous associations between this component and preferences for consumer goods. Specifically, we found a significant main effect of Item Category, $F(1.93, 71.53) = 3.62$, $p = .033$, $\eta_p^2 = .09$. Contrasts showed that LP ($M = -6.64$, $SE = 0.48$) amplitudes were more negative than HP ($M = -5.98$, $SE = 0.46$, $p = .028$); and that MP ($M = -6.77$, $SE = 0.50$) also elicited a larger negativity than HP, $p = .025$. The difference between LP and MP was not significant, $p = .678$. Interactions with A-P or LAT were not significant, Fs < 1.68, ps $> .16$.

Late positivities.

For all the time windows, a main effect of Item Category was found (all $ps<.005$, Bonferroni-corrected, $Fs>9.6$, $\eta_p^2>.20$). No interactions with A-P or LAT were observed, confirming the F-C-P distributed topography depicted in Figure 2. This type of widely distributed topography is similar to previous reports of slow waves relative to motivationally-relevant stimuli (Foti & Hajcak, 2008; Hajcak & Olvet, 2008). We therefore proceeded to break down these main effects in three planned comparisons: HP-LP, HP-MP and MP-LP for every time window. Given that this approach resulted in 15 pairwise comparisons in late positivities, we used Bonferroni corrections to minimize false positives. We found that all the HP-LP contrasts were significant at $p<0.05$ (Bonferroni-corrected), whereas the HP-MP contrasts were significant for 400-800 and 800-1200. The 2000-3000 time window also yielded a statistically significant HP-MP comparison, although its effect size was much smaller than the corresponding HP-LP comparison ($p=.049$ vs. $p=.00024$, respectively, Bonferroni-corrected). MP-LP did not reach corrected significance thresholds.

Effects of subsequent buying decisions

P200/N200.

Analyses on peak-to-peak scores of P200 and N200 amplitudes did not reveal significant effects involving the Buy vs. No-Buy variables.

Late positivities.

Statistical analyses on the main sample of this study (N=38) revealed a significant effect of BNB on all time windows (all $ps=<.01$, Bonferroni-corrected, $10.8 < Fs < 33.98$; $\eta_p^2>.22$, $\eta_p^2<.49$). No interactions with A-P or LAT were observed. Planned subsample analyses revealed that effects involving BNB were never significant if only MP items were considered (all *p*s>.06, uncorrected) (See Supplementary Figure 2). Note that the subsample used for the analyses of MP items (n=26) revealed significant main effects of BNB for all the time windows when all item categories (i.e., LP, MP and HP) were included (all *p*s=<.03, Bonferroni-corrected, *F*s>8.85, *F*s<24.23; η_p^2>.26, η_p^2<.50).

Discussion

The main goal of this study was to examine if ERPs of motivated attention, the N200, the LPP and PSW, were modulated by subjective preferences and buying choices in a virtual shopping task. This study is to our knowledge the first to demonstrate that positive slow waves (PSW) extending up to 3 seconds after the onset of pictures of consumer goods could differentiate between preferred and non-preferred goods. In addition to this finding, we also obtained results consistent with previous research: We found that the N200 was modulated by levels of preference, in accordance with a previous study (Telpaz et al., 2015); and consistent with Pozharliev et al. (2015), we also found that LPP amplitudes were modulated by item preference. Furthermore, we also found that both LPP and PSW amplitudes could differentiate between products that were subsequently "bought" or not by participants. However, subsample analyses revealed that this effect was not significant when only goods with homogenous levels of preferences were considered.

Our results are the first to show that a large and easily detected ERP positivity starting around 300 ms post-stimulus onset and lasting up to 3000 ms co-varies with preferences for consumer goods, expressed in both self-reports and observable choice behaviour. This result could have important implications in the field of consumer neuroscience (or the field of “neuromarketing”) as it indicates that a well-known ERP phenomenon can potentially be seen as a biomarker of consumer preferences, and thus become a useful tool for consumer behaviour (CB) researchers. In addition, the fact that both early and late ERPs were modulated by preferences also indicates that ERPs can provide a variety of indices of consumer preference. However, if ERPs are to become useful indices of CB, it is necessary to understand the functional meaning of specific ERPs associated to consumer preferences. Therefore, to provide a better understanding of the nature of our effects, we discuss below in more detail the potential functional meaning of our findings.

First, the PSW observed after 800 ms in the current study had a larger amplitude for highly preferred items up until 3 seconds post-stimulus onset. The topography of this effect was distributed over fronto-central and centro-parietal sites, as indicated by the absence of significant interactions with the A-P factor. These temporal and topographical properties are similar to slow wave effects observed in studies using emotional scenes or evolutionary-relevant stimuli. For instance, Hajcak and colleagues (Foti & Hajcak, 2008; Hajcak & Nieuwenhus, 2006; Hajcak & Olvet, 2008), using emotional pictures, also observed late effects around similar latencies. In these studies, the topography of late ERP effects also seemed to include both fronto-central and centro-parietal sites, and Hajcak and Olvet (2008) and Foti and Hajcak (2008) also reported an absence of interaction with the anterior-posterior dimension. Post-800 slow waves time-locked to motivationally relevant stimuli are usually interpreted as the manifestation of brain activity related to WM processes (Schupp, Flaisch et al., 2006; Watts et al., 2014). This notion implies that visual emotional information is processed in WM in order to facilitate its elaboration. This point of view is supported by studies showing that PSW effects following the perception of emotional stimuli were linked to attempts at regulating emotions by cognitive reappraisal (Foti & Hajcak, 2008; Hacak & Nieuwenhuis, 2006), which is an activity known to be linked to WM processes (Ochsner, Bunge, Gross, & Gabrieli, 2002; Schaefer et al., 2003).

Further evidence comes from the wider literature on ERPs linked to WM processes, in which it has often been demonstrated that variations in the cognitive load of WM tasks modulate late slow waves (García-Larrea & Cézanne-Bert, 1998; McEvoy, Smith, & Gevins, 1998; Rämä et al., 2000; Ruchkin, Johnson, Mahaffey, & Sutton, 1988; Schupp, Flaisch, et al., 2006; Watts et al., 2014). Although the possibility of a link between our PSW results and WM processes would still need to be established by future research in which WM load is explicitly manipulated, it can be speculated that processes of active maintenance and manipulation of information in WM would be required to facilitate the evaluation and subsequent decision-making about consumer goods. The perception of consumer goods in a shopping context is often linked to elaborative processes leading to a potential choice of whether the product should be purchased or not (e.g. evaluation of costs, evaluation of the utility of the item, comparison with other potential products). Such processes would be very likely to recruit WM processes as they may involve the temporary integration of multiple sources of information, and the active maintenance and manipulation of information, all activities known to recruit WM processes (Braver & Ruge, 2006; De Pisapia, Slomski, & Braver, 2007). Consistent with this possibility, our results indicate that the effects of subjective preference on PSW waveforms were very similar to the effects of subsequent BNB decisions on these waveforms. Although this study is the first to show that PSWs are linked to preferences for consumer goods in a shopping context, future research will be needed to examine whether this effect varies according to differences in decisional consequences of perceiving the goods (e.g. with or without a shopping context).

The effects of preference on the N200 replicated Telpaz et al. (2015), and seem to confirm a growing trend indicating that ERPs occurring in the N200 vicinity reflect processes linked to consumer behaviour (Schaefer et al., 2016; Telpaz et al., 2015). N200 effects are also commonly observed in research using emotional scenes or evolutionary-related stimuli (Olofsson et al., 2008; Walker et al., 2011). It is commonly thought that such effects reflect an early stimulus-driven attentional response (Olofsson et al., 2008; Walker et al., 2011). Telpaz et al. (2015) has suggested that the N200 related to consumer goods could reflect a FRN, a brain potential obtained when participants process decision outcomes that deviate from their expectation (Mushtaq et al., 2016; Schaefer et al., 2016). This explanation could contend that preferred products cause a positive prediction error (PPE), i.e. when an event is “better than expected”. This explanation could potentially account for our results, given that FRN studies have shown that PPEs lead to a smaller (more positive) N200 amplitude (Walsh & Anderson, 2012), such as what we observed for highly preferred products. This explanation is possible and cannot be ruled out by the current experiment. However, in this experiment, the N200 is not time-locked to the outcome of a decision, and predictions are not explicitly elicited before the onset of the stimuli. These are typical conditions under which the FRN is commonly observed (Hajcak et al, 2006), and thus their absence does not support the hypothesis that the N200 that we observed is an FRN. Alternatively, it is not excluded that an attention-related N200 overlaps with the FRN (Holroyd, Pakzad-Vaezi, & Krigolson, 2008). Future research will be needed to disentangle these two explanations.

We also observed an effect of preference on a positivity in the 400-800 time window corresponding to the latencies of the LPP. This result is consistent with Pozharliev et al. (2015) although we found this effect when participants were alone in the room, whereas Pozharliev et al. report an LPP associated to luxury vs. non-luxury items only when participants were in a social context. The procedures used in the two studies are too different to draw definitive conclusions about this potential contradiction, but it could be speculated that the possibility of buying products in the current study may have enhanced the motivational engagement towards preferred products, which could potentially explain this difference. This result is also consistent with a study that found a greater LPP for written words referring to brand names that were liked (Bosshard et al., 2016) and a study that found a greater positivity between the 400-1000 latencies while participants were shown cheap vs. expensive prices during a virtual shopping task (Schaefer et al., 2016). Overall, these results indicate that late ERP positivities may index neural processes related to consumption behaviours.

An important feature of the LPP observed in the current study is that it clearly involves fronto-central sites, while also including centro-parietal sites. Many studies using classical emotional stimuli found an LPP visible in both anterior and posterior sites but these studies also showed that LPP amplitudes tended to be larger in posterior sites (e.g. Schupp, Stockburger et al, 2006). Interestingly, some studies have found an LPP with a more fronto-central topography (Cunningham, Espinet, DeYoung, & Zelazo, 2005; Gable & Harmon-Jones, 2010, 2013) . One potential explanation for this difference lies in the differences in stimuli content. Classic emotion ERP studies tend to use visual stimuli sets with high proportions of simple, intrinsic emotional stimuli that can convey emotional meaning through very simple and crude perceptual pathways (Mermillod et al, 2010). Studies that found a more distributed or fronto-central LPP tend to have used more complex motivationally-relevant stimuli such as desirable appetitive stimuli (food-related, drug-related cues for craving addicts, etc.) or more complex verbal stimuli (Cunningham et al., 2005). It is thus possible that the systematic differences in LPP topography reflect the complexity of information needed to recognize stimuli. Most modern consumer goods are also likely to require the access to both perceptual and semantic information to be identified, which could potentially explain why the topography of 400-800 effects were atypical when compared to classic emotion ERP studies.

Overall, these results tentatively suggest the existence of a multi-stage process of evaluating motivationally-relevant consumer goods that share several similarities with processes of motivated attention usually associated to classical emotional stimuli. First, early attentional processes would allow a very quick orientation of attentional resources on preferred goods. This process is likely to rely on the detection of stimulus properties that have acquired motivational relevance through prior learning. Next, a more overt attentional response would facilitate the conscious identification of the stimulus, through processes that probably rely on the integration of multiple sources of information including perceptual and semantic information. Finally, processing resources are selectively allocated to the stimulus in a temporally extended manner in order to facilitate a more elaborative form of processing which is likely to be linked to the evaluative and decisional constraints of viewing consumer goods. This tentative framework has very strong overlaps with sequential models of motivated attention in the context of emotion research (Schupp, Flaisch et al., 2006). Although early and late ERPs of motivated attention are widely considered as serving distinct functions, it would be inaccurate to consider them as a fully independent. In most cases these different processing stages are likely to be part of an overarching single process (Schupp, Flaisch et al., 2006; Watts et al., 2014). Specifically, an automatic orientation towards motivationally relevant stimuli, and its subsequent overt identification can be reasonably seen as causal antecedents of their maintenance in WM for further processing and elaboration (Watts et al., 2014). However, an important caveat to our interpretation is that it relies in part on the similarity of the morphology of our ERP data with results obtained in other studies using intrinsically emotional stimuli. Even though an important body of research on the neural correlates of motivated attention strongly supports our explanation, further ERP experiments will be needed in which different stages of processing of consumer goods are systematically manipulated (e.g. WM load, decisional demands, etc.) to consolidate this knowledge.

Furthermore, a number of potential limitations need to be discussed in more detail. First, the construct of consumer preference used in our study is constrained by our operationalization of preferences in terms of "wanting" self-reports and buying choices. Wanting self-reports have been used previously to operationalize preference in consumer neuroscience studies (Knutson et al., 2007; Schaefer et al., 2016) and were chosen because of their conceptual overlap with our definition of economic value, that is, the potential benefits brought by obtaining an object. Second, observable buying choice is an objective measure of preference, but also the end goal of most instances of consumer behaviour, and as such it has often been used to investigate neural correlates of consumer preference (e.g., Knutson et al., 2007; Plassmann et al., 2007; Schaefer et al., 2016). However, we do acknowledge that other methods to estimate preference do exist (willingness to pay, choice modeling, etc.), and future research will be needed to explore relationships between ERPs and these other methods.

Second, it could be argued that our approach of providing a schedule of incentives to buy products creates a somewhat unrealistic environment. As explained in the methods section, this feature of our procedure was introduced to prevent strategies based on "buying" a single product or only a restricted set of products. We acknowledge that this feature creates a situation where there is no absolute freedom of choice, but rather a *relative freedom* of buying choice in which a buyer receives incentives to buy a certain amount of products from a set list. However, many real-life shopping situations conform to a relative freedom situation, as often shoppers' consumption behaviours are driven by the need to purchase a set number of products amongst an available choice (e.g. going to the closest supermarket to buy a set list of many household items because they are running out).

Third, it could be argued that the fact that participants can truly purchase only one randomly picked product creates an unrealistic situation. This procedure has been previously used in other simulated shopping tasks (Knutson et al., 2007; Plassmann et al, 2007; Schaefer et al., 2016) to increase the realism of the shopping situation compared to tasks in which purchasing is completely fictitious. This approach is particularly useful in neuroimaging experiments in which multiple trials (often hundreds) are needed to improve the signal to noise ratio (SNR) of brain activity, as providing funding to the purchase of hundreds of products in a psychological experiment would be unrealistic in most cases. Future developments in this field of research could potentially address this issue, such as EEG measurements during real shopping environments with portable EEG systems, although this approach poses additional challenges, such as how to address movement artifacts, accurate synchronization between EEG recordings and the onset of visual stimulation, etc.

Fourth, it could be argued that the ERP effects observed in our study could reflect emotional feelings towards products, rather than processes of motivated attention. This would be a reasonable interpretation, as it is well understood that preferred products can elicit positive affect (e.g., Walla et al., 2011). We acknowledge that our study cannot formally rule out this explanation. However, previous research on ERP late positivities does not plead in favour of this alternative account. Although late ERP positivities can easily differentiate between emotional and non-emotional stimuli, they are typically unable to reliably differentiate between negative and positive pictorial stimuli (e.g. Schupp et al., 2000). Instead, much evidence seems to indicate that ERP positivities similar to those observed in the current study (N200, LPP and PSW) are best understood as neural correlates of selective attention towards motivationally relevant stimuli (Codispoti et al., 2007; Junghöfer, Bradley, Elbert, & Lang, 2001; Schupp, Flaisch, et al., 2006; Schupp, Stockburger, et al., 2006; Schupp et al., 2004). However, we do acknowledge that the question of the emotional feelings elicited by the perception of consumer goods is important. Future research will be needed to fully address this issue in which studies are designed specifically to test this question.

In summary, this study is the first to show that the perception of preferred consumer goods in a virtual shopping task is linked to late positive slow waves extending up to three seconds following stimulus onset. In addition, we replicated previous results that had shown that preference for consumer goods modulated early ERP components (e.g. N200, Telpaz et al, 2015) and the LPP (Pozharliev et al, 2015). Furthermore, the overall pattern of the results seems to confirm that ERPs to consumer goods are very similar to well-known ERPs of motivated attention usually observed with intrinsically emotional stimuli. Based on previous research on the ERP correlates of selective attention, we tentatively suggest that early ERPs (e.g. the N200) to consumer goods could be indicative of preferences driven by unconditional and automatic processes, whereas later ERPs such as the LPP and the PSW could reflect preferences built upon more elaborative and conscious cognitive processes.

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