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Nicotine enhances an auditory Event-Related Potential component which is inversely related to habituation

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Abstract:	<p>Nicotine is a psychoactive substance that is commonly consumed in the context of music. However, the reason why music and nicotine are co-consumed is uncertain. One possibility is that nicotine affects cognitive processes relevant to aspects of music appreciation in a beneficial way. Here we investigated this possibility using Event-Related Potentials (ERPs). Participants underwent a simple decision-making task (to maintain attentional focus), responses to which were signaled by auditory stimuli. Unlike most previous research looking at the effects of nicotine on auditory processing, we used tones of different pitch, a fundamental element of music. In addition, unlike most other studies, we tested non-smoking subjects to avoid withdrawal-related complications. We found that nicotine (4.0 mg, administered as gum) increased P2 amplitude in the frontal region. Since a decrease in P2 amplitude and latency is related to habituation processes, and an enhanced ability to disengage from irrelevant stimuli, our findings suggest that nicotine may cause a reduction in habituation, resulting in non-smokers being less able to adapt to repeated stimuli. A corollary of that decrease in adaptation may be that nicotine extends the temporal window during which a listener is able and willing to engage with a piece of music.</p>

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13 **Nicotine enhances an auditory Event-Related Potential**
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16 **component which is inversely related to habituation**
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Abstract

Nicotine is a psychoactive substance that is commonly consumed in the context of music. However, the reason why music and nicotine are co-consumed is uncertain. One possibility is that nicotine affects cognitive processes relevant to aspects of music appreciation in a beneficial way. Here we investigated this possibility using Event-Related Potentials (ERPs). Participants underwent a simple decision-making task (to maintain attentional focus), responses to which were signaled by auditory stimuli. Unlike previous research looking at the effects of nicotine on auditory processing, we used complex tones that varied in pitch, a fundamental element of music. In addition, unlike most other studies, we tested non-smoking subjects to avoid withdrawal-related complications. We found that nicotine (4.0 mg, administered as gum) increased P2 amplitude in the frontal region. Since a decrease in P2 amplitude and latency is related to habituation processes, and an enhanced ability to disengage from irrelevant stimuli, our findings suggest that nicotine may cause a reduction in habituation, resulting in non-smokers being less able to adapt to repeated stimuli. A corollary of that decrease in adaptation may be that nicotine extends the temporal window during which a listener is able and willing to engage with a piece of music.

Keywords: music, pitch, nicotine gum, ERPs, P2 amplitude

Introduction

Nicotine is a psychoactive substance that is commonly consumed in the context of music. Cigarettes are prevalent among young adults (Conrad et al., 1992) and college students (Wechsler et al., 1998), a demographic that is known to be most engaged with music (Hargreaves & North, 1997) and to attend music festivals (Packer & Ballantyne, 2010; Woodward et al., 2014), where nicotine products are consumed (Mackul'ak et al., 2015). However, the reason why music and nicotine are co-consumed is uncertain. One possibility is that nicotine affects cognitive processes relevant to aspects of music appreciation in a beneficial way. Previous research has established that cholinergic systems are important for cognitive functioning and nicotine is a potent cholinergic stimulant that affects many central nervous system (CNS) pathways, including the auditory pathway (Crawford et al., 2002). Nicotine has been reported to improve attention, learning, reaction time (RT), problem solving, and stimulus evaluation and discrimination (Heishman et al., 1994; Le Houezec & Benowitz, 1991; Wesnes & Warburton, 1983).

Many of nicotine's performance-enhancing properties can be explained through its ability to shift brain-state arousal (Heishman et al., 2010; Wesnes & Warburton, 1983). That is, many of the cognitive improvements seen with nicotine are thought to be indirectly mediated by its mood-elevating and physiological arousal-inducing properties (Newhouse et al., 2004; Waters & Sutton, 2000), and indeed smokers have reported that arousal control is one motive for nicotine use (Gilbert, 1979). Several neuroscientific studies investigating nicotine's effects on auditory perception have confirmed nicotine's ability to enhance arousal and attention using functional magnetic resonance imaging

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2
3 (fMRI) (Smucny et al., 2015; Thiel & Fink, 2007) and magnetencephalography (MEG)
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5 (Otsuru et al., 2012). Electrophysiological techniques, for example Event-Related
6
7 Potentials (ERPs), have also supported nicotine's role as an enhancer of arousal and
8
9 attention (Harkrider & Champlin, 2001).
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13 In relation to auditory information processing, ERP components P1, N1, P2, and
14
15 N2, are particularly implicated in arousal and attention. P1 occurs approximately 50 ms
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17 after the onset of a stimulus (Key et al., 2005) and is strongly affected by stimulus factors,
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19 such as intensity (Kaskey et al., 1980), as well as arousal (Harkrider & Champlin, 2001).
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21 Component N1 occurs approximately 100 ms after stimulus onset and is also affected by
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23 arousal (Harkrider & Champlin, 2001). In addition, it is enhanced by increased selective
24
25 attention to basic stimulus characteristics (Hillyard et al., 1973).
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30 P2 occurs approximately 180-250 ms after stimulus onset (Friedman & Meares,
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32 1980). This component shares many characteristics with N1 and as such they are often
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34 examined together as the N1-P2 complex. For example, P2 is also implicated in arousal
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36 and attention (Harkrider & Champlin, 2001) and is sensitive to physical characteristics of
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38 stimuli, including pitch (Novak et al., 1992). Furthermore, it is sensitive to habituation
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40 processes (Ritter et al., 1968; Rust, 1977) and decreases as an indication of more efficient
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42 stimulus filtering (Knott, 1989). Finally, N2 occurs between 180-325 ms following the
43
44 onset of auditory stimuli (Patel & Azzam, 2005). It is modulated by arousal and attention
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46 (Harkrider & Champlin, 2001) and is also associated with response inhibition (Jodo &
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48 Kayama, 1992; Kaiser et al., 2006).
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53 Nicotine has been shown in previous studies to affect all 4 of these components of
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55 the auditory ERP (P1, N1, P2, and N2). P1, the component implicated in arousal and
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3 known to be sensitive to stimulus factors (Kaskey et al., 1980), has been shown to
4 increase in amplitude in studies examining nicotine's effect on abstinent smokers using
5 auditory stimuli (Knott, 1985b). However, others (e.g. Friedman & Meares, 1980) have
6 failed to find a similar effect, and hence nicotine's effects on auditory-related arousal as
7 measured by this component is unclear. Indeed, the cognitive function most consistently
8 affected by nicotine is attention (Newhouse et al., 2004; Stolerman et al., 1995). One
9 aspect of attention that is particularly influenced by nicotine is selective attention. N1, the
10 ERP component strongly associated with attention, consistently increases in amplitude
11 during auditory tasks of selective attention (Hillyard et al., 1973). In general, this effect is
12 further enhanced by nicotine (Knott, 1985b, 1986), reflecting the drug's ability to
13 improve attentional processes (Hillyard & Picton, 1979). P2, the component implicated in
14 habituation processes (Ritter et al., 1968; Rust, 1977), consistently decreases as a result
15 of nicotine in auditory tasks of selective attention (Friedman et al., 1974a; Knott & Harr,
16 1995). This may reflect a more efficient filtering process and an enhanced ability to
17 disengage from irrelevant stimuli (Knott, 1985a, 1989).

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39 The N2 component occurs in response to attended and unattended deviants and
40 can reflect disparity between a deviant stimulus and a sensory-memory representation of
41 the target stimulus. Early research with this component (Picton & Hillyard, 1974; Picton
42 et al., 1974) suggests the amplitude of the auditory N2 to be inversely related to
43 behavioral arousal and therefore to be significantly smaller during high activation states
44 (Knott, 1989). Initial reports examining the influence of nicotine on ERPs using auditory
45 stimuli reported a reduction of the P2-N2 wave. However, other studies have found no
46 effect of nicotine on the amplitude of the N2 component and P2-N2 complex (Knott,
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3 1985b; Knott et al., 1995), again suggesting (as with P1) some uncertainty concerning
4 nicotine's action on this component and hence on the underlying cognitive processes.
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8 In addition to the considerable uncertainty over nicotine's effects on certain ERP
9 components (P1, N2), previous studies examining the effects of nicotine on auditory
10 information processing have three significant problems, particularly in relation to music
11 perception. Firstly, many studies have used an abstinent smoker population. Hence,
12 where relevant, it is unclear whether nicotine's effects on cognitive processes are a result
13 of the reversal of withdrawal or a true interaction with some aspect of auditory perception
14 and cognition. Secondly, some studies have used pulses and clicks as opposed to tones
15 (e.g. Friedman et al., 1974b; Harkrider & Champlin, 2001; Knott et al., 2009). Pulses and
16 clicks lack the physical dimensions of music (e.g. loudness, pitch). Therefore, sound
17 stimuli that incorporate a musical dimension may facilitate auditory perception better
18 than pulses and clicks, and may therefore be more sensitive to the effects of nicotine.
19 Finally, those studies that have used tones have only used pure tones (e.g. Friedman et al.,
20 1974a; Friedman & Meares, 1980; Knott, 1985a; Domino & Kishimoto, 2002; Jodo &
21 Kayama, 1992), which are rare in music, and most have used only manipulated intensity
22 (loudness) (e.g. Knott, 1985b). Another dimension of music, which has yet to be
23 examined, is pitch, a fundamental element of music (Spencer & Temko, 1988). The basic
24 perceptual mechanisms involved in pitch processing and how pitch is analyzed by the
25 auditory system is well established (McDermott & Oxenham, 2008). For example, we
26 know that variations in pitch (e.g. high pitch, low pitch) are easy to perceive and
27 discriminate (McAdams, 1989). Therefore, the current study will use pitch in
28 combination with complex tones in order to investigate how nicotine affects auditory
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3 perception and cognition.
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6 The aim of the present study is to test whether nicotine affects auditory
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8 information processing in non-smokers, and if so, to identify which cognitive
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10 mechanisms underlie the effect, in order to better understand the co-consumption of
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12 music and nicotine. Several different paradigms have been used to test the effects of
13
14 nicotine on auditory perception in non-smokers, including passive listening (Harkrider &
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16 Champlin, 2001), discrimination (Knott et al., 2009a) and dichotic listening (Knott et al.,
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18 2009b). Again, this variation may account for the different ERP results found across
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20 these studies. With this mind, a simple and repetitive task was employed for the current
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22 study where participants were asked to make a decision based on the combination of
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24 auditory and visual stimuli presented. A decision-making paradigm requires attention
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26 (and hence keeps participants focused on listening to the auditory stimuli) while stimulus
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28 repetition is conducive to habituation. This allows us to assay these cognitive
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30 mechanisms during nicotine and placebo conditions.
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Method

Participants

Initially, 36 (18 male) participants were recruited with a mean age of 21.33 years, (SD = 3.25; range 18 – 29). Four participants were subsequently excluded due to lack of ERP responses or electrical noise during data acquisition, hence the data presented below is the result of the remaining 32 participants (16 per group). Participants either received credits as undergraduate psychology students or were paid £10 for one hour and fifteen minutes of their time. The research protocol met the ethical requirements of the University of Sheffield's Ethics Committee.

All participants were free of neurological and psychiatric illnesses based on self-reports and none were pregnant or breastfeeding, all contraindications against the use of nicotine gum (Baldeweg et al., 2006). No participants reported substance dependence and none were taking medication (with the exception of an oral contraceptive). All participants were native English speakers with minimal exposure to secondary languages. Language background was controlled for because it is known to strongly influence auditory processing (Salmelin et al., 1999; Vihla et al., 2002) and exposure to a tonal language is particularly known to increase pitch perception (Krishnan et al., 2005). Therefore, competency of secondary languages was assessed through self-reports of listening, speaking, reading, and writing. Those who considered themselves to be above 'fair' in term of their listening, speaking, reading, and writing of a second language were excluded from participation. Volunteers were also excluded if they reported any experience with a tonal language, such as Mandarin or Vietnamese.

In order to control for hemispheric specialization (Alexander & Polich, 1997) and

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3 to conform to previous research methods (Wioland et al., 1999), all participants were
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5 right-handed, as defined by a score of 80-100% on the Edinburgh Laterality Test
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7 (Oldfield, 1971). Furthermore, because musical training has been repeatedly shown to
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9 improve pitch processing (Besson et al., 2007), and musicians in particular are thought to
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11 have superior pre-attentive auditory processing (Koelsch et al., 1999), musicians were
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13 excluded from the study. All participants were non-musicians defined as having no
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15 regular experience with playing a musical instrument and no musical training beyond
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17 mandatory music lessons in primary and secondary school.
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22 Lastly, in order to avoid the potential confounding effects of pre-exposure to
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24 nicotine, all participants were non-smokers. Participants were required to be entirely
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26 nicotine free for at least one year. This included habitual as well as occasional use, such
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28 as social smoking and shisha.
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32 33 34 *Pure tone audiometry*

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36 A Pure Tone Audiometry (PTA) hearing test was used to check for any signs of hearing
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38 loss and to confirm that participants could detect stimuli. The PTA hearing test was used
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40 based on previous research by Light and colleagues (2010). The test was performed at
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42 ~80dB SPL and consisted of tones at 125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz,
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44 8000Hz, and 10,000Hz. The test was performed twice, once in each ear. Participants
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46 would have been excluded if they were unable to detect any tones in either ear or if they
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48 had gross abnormalities or asymmetries in their hearing between ears. No participants
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50 were excluded for these reasons.
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Auditory stimuli

Sound stimuli were constructed based on previous research examining auditory perception using ERPs and mismatch negativity (MMN) (Baldeweg et al., 2006; Tervaniemi et al., 2005). Sound stimuli consisted of two spectrally complex tones, one high and one low. The high pitch tone consisted of its fundamental frequency, 523.25Hz (C5 on the Western scale) and its following four overtones of the harmonic series: 1046.50Hz, 1567.98 Hz, 2093.00Hz, and 2637.02Hz (C6, G6, C7, and E7 respectively on the Western scale). The low pitch tone consisted of its fundamental frequency, 130.81Hz (C3) and its following four overtones of the harmonic series: 261.63 Hz, 392.00 Hz, 523.25Hz, and 659.25 Hz (C4, G4, C5, and E5 respectively). The tones contained harmonics as previous behavioral and neural research have shown complex tones to better facilitate pitch processing compared to fundamental frequencies only (Tervaniemi et al., 2000a; Tervaniemi et al., 2000b). The stimuli were synthesized using Ableton Live 9.1 Suite, a software music sequencer, on a Macbook Pro, 2014. All sounds had a presentation time of 300 ms with a 5 ms rise and fall time, similar to previous research methods (Koelsch et al., 1999). Sounds were presented binaurally via insert earbuds at ~80dB SPL.

Procedure

Prior to the experiment, participants undertook a health screening questionnaire to determine their eligibility to participate. Upon approval, participants were asked to refrain from all products containing nicotine, caffeine, and alcohol for 24 h before the experiment. At the start of the EEG study participants were randomly assigned to either

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3 the nicotine or placebo condition and were given the appropriate piece of gum to chew,
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5 either nicotine (4 mg nicotine polacrilex gum - Boots NicAssist ice mint flavored gum; N
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7 = 16) or placebo (Wrigley's Extra peppermint flavored chewing gum, having similar size,
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9 shape, and colour to the nicotine gum; N = 16). Participants were instructed to chew the
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11 gum on a chewing-resting cycle of 30 s. That is, they chewed the gum for 10 s, then
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13 rested the gum on the inside of the cheek for 20 s. This cycle – the chewing method used
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15 previously in nicotine research (e.g. Ernst et al., 2001) – was repeated for 25 min. Resting
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17 the gum inside the cheek allows the nicotine to gradually be absorbed by the buccal
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19 mucosa and released into the blood stream. Four milligram nicotine gum yields levels
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21 comparable to smoking a commercial cigarette and it stays in the blood stream for over
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23 120 min (Benowitz et al., 1988).
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29 To help participants stay on task during the chewing-resting cycle, a video was
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31 played that mirrored the action of chewing or resting. When the subject was to chew gum,
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33 a high tone bell rang and an image of a mouth chewing gum appeared. When the subject
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35 was to rest, a low alarm tone sounded and an image of a stop sign with a halt hand in the
36
37 centre appeared. While participants were engaged in the chewing-resting cycle, they were
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39 fitted with the EEG net and the sensors were checked for impedance levels. At the end of
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41 the 25 min, a final image of a chewed piece of gum appeared and a message over the top
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43 read “Please spit out gum”. At this time participants discarded the gum and prepared to
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45 begin the auditory perception task. They did this by centering themselves 50 cm in front
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47 of the computer screen and by having earbuds fitted into their ears and checked for sound.
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53 For safety reasons, adverse effects were also monitored through self-report. Upon
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55 completion of the chewing-resting cycle, participants were administered the Subjective
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3 Treatment Emergent Symptom Scale (STESS) that assesses the physical reactions to
4 nicotine and the severity of these reactions (Guy, 1976). Participants with scores of 50%
5 or more on any of the four subscales were discontinued from the study. Two participants
6 were discontinued for this reason and were replaced.
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13 Before beginning the task, participants were introduced to general aspects of the
14 experimental procedure. Participants were told that a fixation cross would appear on the
15 computer screen, followed by a sound. After this an image of two arrows facing in
16 opposite directions (one up, one down – the up and down arrows could be on the left or
17 on the right) would appear and that based on the arrangement of these arrows they would
18 be asked to indicate a response on a keypad using their index fingers. They were also told
19 that after their response the procedure would repeat.
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29 Participants were then introduced to the auditory and visual stimuli used in the
30 experiment, which were presented using E-prime 2.0 software (Psychology Software
31 Tools, Pittsburgh, PA). Participants first listened to the high pitch and low pitch tones
32 separately. Next, participants were shown the arrow images and further details of the
33 procedure were explained, namely that they would hear a tone (either high pitch or low
34 pitch) followed by one of the arrow images. If they heard a high pitch sound, they were to
35 focus on the position of the up arrow. If the up arrow was positioned on the left-side of
36 the image, then they were to press '1' on the keypad; if the up arrow was positioned on
37 the right-side of the image, then they were to press '4'. Alternatively, if they heard a low
38 pitch sound, they were to focus on the position of the down arrow. If the down arrow was
39 positioned on the left-side of the image, then they were to press '1'; if the down arrow
40 was positioned on the right side of the image, then they were to press '4'. Figure 1
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3 illustrates this procedure and displays the duration (in ms) of each event.
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6 In order to record the highest quality of EEG data, participants were requested to
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8 refrain from blinking as best they could during presentation of the fixation cross and
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10 sound and instead to try to blink during the arrow images or while responding with the
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12 keypad. After these verbal instructions, the lights were turned off and participants were
13
14 left alone in the room. In order to reiterate the experimental instructions, the procedure
15
16 for the experiment was written out on the computer and participants were given practice
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18 trials consisting of two blocks of 8 trials each. After practicing, the experiment began,
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20 consisting of 4 blocks of 100 trials each. In between each block, participants were
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22 allowed to rest for as long as they liked. Rest periods were employed in order to
23
24 maximize concentration during the experiment. At the end of the experiment participants
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26 were detached from the EEG net and debriefed.
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34 *Data acquisition*

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36 Electrophysiological data were recorded continuously from the scalp using a 128-channel
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38 Geodesic Sensor Net (GSN) (Tucker, 1993) from Electrical Geodesics, Inc. (EGI, Eugene,
39
40 Oregon). The GSN is a lightweight knitted network of elastic threads that house
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42 electrodes in small plastic pedestals. Inside each pedestal is an Ag/AgCl synthetic sponge
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44 sensor that serves to detect and record the electrophysiological data. The sponges are
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46 soaked in a solution of potassium chloride (KCl) in order to render them conductive
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48 (Casanova et al., 2012). The GSN has an even inter-electrode distance of 2.7 cm and a C_z
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50 reference at the vertex of the scalp (Sabbagh et al., 2004). The six most anterior
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52 electrodes of the GSN record the horizontal and vertical electroculogram (EOG),
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3 monitoring eye movements and blinks. The GSN connects to the EGI high-input
4 impedance amplifier (200 MOhm, Net Amps, Electrical Geodesics, Inc., Eugene,
5 Oregon) with an in-line finite impulse response (FIR) bandpass filter of 0.1 Hz – 400 Hz.
6 Individual electrodes were adjusted in order to keep impedance below 50 k Ω , as
7 recommended by the manufacturer. Channel signals were amplified x 1000 and digitized
8 with a 12-bit A/D converter at a sampling rate of 1000 Hz (1 ms samples). The EEG data,
9 as well as event onset times, were collected and stored on a Macintosh G4 (10.2.8) using
10 EGI Net Station 4.1.2 for further analysis. **Data acquisition sessions lasted for approx-**
11 **imately 30 min for a typical recording.**
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27 *Data Analysis*

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29 Subsequent processing and analyses were performed offline. Data were digitally filtered
30 with a bandpass of 1-50 Hz. A high pass-filter of 1 Hz was used in order to exclude any
31 slow direct current shifts, while a low pass-filter of 50 Hz was used in order to remove
32 any mains interference. Segmentation of the continuous EEG data was performed using
33 an epoch that began 100 ms prior to the onset of the sound stimulus and ended 400 ms
34 after. Next, artifacts were removed from the epochs. This was first achieved
35 automatically by employing Net Station's artifact detection routine. That is, individual
36 channels within each epoch were marked as 'bad' if they contained either zero variance, a
37 fast average amplitude exceeding 200 μ V, or a differential average amplitude exceeding
38 200 μ V. Furthermore, individual epochs were rejected if they contained eye movements,
39 identified by a maximum to minimum differential of 70 μ V, or blinks, identified by a
40 maximum to minimum differential of 100 μ V. All segments were then subjected to a
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3 visual inspection in order to identify and remove any remaining artifacts that did not
4 exceed the threshold values. Individual segments were rejected if they contained more
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6 than 10 bad channels. For the remaining segments, individual bad channels were replaced
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8 with a spherical spline algorithm (Srinivasan et al., 1996), which interpolates data for bad
9
10 channels using data of the surrounding channels. 90% of the segments were retained. **The**
11
12 **number of artifact-free epochs was comparable across groups (placebo, high pitch: $M =$**
13 **142.00, low pitch: $M = 141.27$; nicotine, high pitch: $M = 151.19$, low pitch: $M = 151.81$).**
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20 The remaining trials were then segregated by condition (high pitch; low pitch) and
21 averaged for each participant. The ERPs obtained for both high pitch and low pitch
22 stimuli were taken regardless of whether the correct keypad response was given by the
23 participant, because the decision-making aspect of the experiment and the subsequent
24 response was only used to keep participants focused on listening to the auditory stimuli
25 and to conceal the true nature of the experiment.
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34 Next, all ERPs were baseline-corrected. This was performed for each channel by
35 taking the average of all the samples within the 100 ms of pre-stimulus data and
36 subtracting it from all the remaining samples (stimulus onset to 400 ms post-stimulus).
37
38 Finally, the individual participants' ERPs were re-referenced in order to correct for the
39 polar average reference effect (PARE; Junghöfer et al., 1999). **Voltage measurements**
40 **from EEG are measurements of the difference in potential between the site being**
41 **measured (a specific electrode) and the reference site (C_z), which is assumed to have a**
42 **voltage of zero. However, the surface of the scalp is unevenly sampled because**
43 **electrodes are concentrated on the top of the head. This causes the average reference to be**
44 **biased towards the top of the head and results in differences in the average to be smaller**
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3 at the vertex than at the periphery. This bias - the PARE - must be corrected. Using a
4 spherical spline interpolation, the voltages of the surface of the scalp not covered by
5 electrodes can be estimated. Using the results from this interpolation, a PARE-corrected
6 average reference was calculated for the entire surface of the scalp. After re-referencing,
7 group averages of ERPs were calculated separately for the nicotine and placebo groups
8 for both the high pitch and low pitch conditions.
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20 *Statistical analysis*

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22 The ERP components of interest were P1, N1, P2, and N2. They were identified through
23 visual inspection of group averages and individual data. Furthermore, they were found to
24 be most distinct and of largest absolute amplitude in the frontal and central regions of the
25 scalp. The time windows chosen for each component were based on previous literature
26 (Key et al., 2005; Picton & Hillyard, 1974) as well as visual inspection of the data. These
27 were: P1, 30-70 ms; N1, 80-120 ms; P2, 140-200 ms; N2, 240-300 ms.
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36 The mean amplitude and latency of the P1, N1, P2, and N2 components from the
37 frontal and central regions of the scalp were statistically analyzed for the left, central, and
38 right areas. For the left and right areas of the frontal and central regions a group of
39 channels (electrodes) were averaged together to derive the mean amplitude and latency of
40 each group of channels. Averaging a group of neighbouring electrodes is a standard
41 approach taken in ERP analyses (Baruth et al., 2010; Picton et al., 2000) and is done in
42 order to improve the signal to noise ratio, thereby increasing the statistical power of the
43 data (Oken & Chiappa, 1986). These channel groups and their relation to the 10-20
44 International System (Jasper, 1958) are presented in Figure 2. The channel groups for the
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3 left and right areas of the frontal region (those areas circled in Figure 2) were based on
4 those used in previous research (Baruth et al., 2010; Casanova et al., 2012; Maitre et al.,
5 2012). These areas correspond to F_3 and F_4 of the 10-20 International System and are
6 therefore given these names in the current study, and along with F_z formed the channels
7 of interest for the frontal region. The channel groups for the left and right areas of the
8 central region (those areas squared in Figure 2) were also based on previous literature
9 (Maitre et al., 2012; Yokota et al., 2014). However, compared to previous literature, the
10 current study's grand average waveforms showed the left and right areas of the central
11 region to have maximal activation closer to the vertex. Therefore, the channel groups
12 used for these areas have been moved inward compared to past research. For this reason,
13 C_3 and C_4 of the 10-20 International System are not contained within the central region's
14 left and right channel groups, respectively. However, because these groups approximately
15 correspond to C_3 and C_4 they are given these names. C_z (also channel of interest in the
16 central region) in the current study corresponds to C_z of the 10-20 International System
17 and therefore is given this name.

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Peak amplitudes in individual subject's ERPs were found within the time window and peak latency was calculated relative to the stimulus onset. Where channels were grouped, the peak amplitude and latency from all electrodes in a channel group were averaged. Figure 3 shows those waveforms used in the current analysis - the peripheral waveforms are representative of each channel group (and F_z and C_z) and show the characteristic ERP components P1, N1, P2, and N2. These data are shown again on a larger scale in Figure 4.

For each individual participant, the amplitude was calculated for each component

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3 (P1, N1, P2, N2) in each region of interest (frontal/central; left, center, right - F_z and C_z
4 constitute 'centre' here) and was then analyzed by means of a repeated-measures analysis
5 of variance (ANOVA). This same procedure was repeated for latency information. This
6 led to 16 separate ANOVAs: 4 components x 2 ERP measurements x 2 scalp regions. For
7 each ANOVA, there were two within-subjects factors: 1) Sound (high pitch and low
8 pitch) and 2) Area (left, right, and central). There was also one between-subject factor,
9 drug condition (placebo or nicotine). Where variables were found to violate the
10 assumption of sphericity a Greenhouse-Geisser correction was used. Probabilities at the
11 level of $p < 0.05$ were considered to be significant. For post-hoc analyses, Bonferroni
12 correction was employed.
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Results

ERP data

The grand average waveforms for the high pitch and low pitch conditions at the chosen recording sites are presented for the nicotine and control group in Figure 3. An expanded waveform can be viewed for the frontal areas, F₃, F_z and F₄ as well as for the central areas, C₃, C_z and C₄ in Figure 4. Furthermore, the mean amplitude and latency values for each component by condition and area are presented separately for the frontal (Figure 5) and central (Figure 6) regions.

P1: The amplitude and latency of the ERP components P1, N1, P2, and N2 was selected for statistical analysis as previously described. Repeated measures ANOVAs with 3 factors (pitch condition, area, and drug group) were performed separately for the frontal and the central regions, and revealed some significant findings. For P1 amplitude in the frontal region, there was a main effect of area, $F(2, 52) = 6.21, p = 0.01, \eta^2 = 0.19$, where P1 amplitude at F_z was significantly larger ($M = 0.95, SE = 0.12$) than F₃ ($M = 0.73, SE = 0.10$), $p = 0.01$. For P1 amplitude in the central region, there was also a main effect of area, $F(2, 58) = 5.23, p = 0.008, \eta^2 = 0.15$, where P1 amplitude at C_z was significantly larger ($M = 0.76, SE = 0.10$) than C₃ ($M = .62, SE = .08$), $p = 0.02$.

For P1 latency in the frontal region, there was a main effect of area, $F(2, 52) = 3.39, p = 0.041, \eta^2 = 0.12$. However, post-hoc tests revealed no significant differences between F₃ ($M = 46.85, SE = 2.00$) and F_z ($M = 49.01, SE = 1.82$), $p = 0.480$, between F₃ and F₄ ($M = 50.87, SE = 1.78$), $p = 0.106$, or between F_z and F₄, $p = 0.482$. For the P1 latency in the central region no significant effects were found.

In summary, P1 amplitude was larger at the midline (F_z and C_z) compared to the

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3 left and right hemispheres. However, neither nicotine nor pitch affected P1 amplitude or
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6 latency. The main effect of area can be viewed in waveform and topographic form in
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9 Figures 4 and 7 respectively (the data are further summarized in Figures 5 and 6).

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11 **N1:** For N1 amplitude in the frontal region, there was a main effect of pitch, $F(1,$
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13 $28) = 6.20, p = 0.02, \eta^2 = 0.18$, where N1 for low pitch had a significantly larger
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15 amplitude ($M = -1.85, SE = 0.25$) than high pitch ($M = -1.47, SE = 0.15$). For N1
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17 amplitude in the central region, there was a main effect of area, $F(2, 58) = 4.34, p = .018,$
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19 $\eta^2 = 0.13$, where N1 amplitude at C_z was significantly larger ($M = -1.92, SE = 0.22$) than
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21 C_3 ($M = -1.62, SE = 0.17$), $p = 0.027$. There was also an interaction of area and drug
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23 group, $F(2, 58) = 3.59, p = 0.034, \eta^2 = .11$. However, post-hoc tests revealed no
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25 significant differences between drug groups in N1 amplitude at $C_3, F(1, 30) = 1.43, p =$
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27 $0.24, C_z, F(1, 30) = 0.52, p = 0.48$, or $C_4, F(1, 30) = 0.00, p = 1.00$.

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32 For the N1 latency in the frontal region, there was a main effect of pitch, $F(1, 28)$
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34 $= 18.81, p = .000, \eta^2 = 0.40$. High pitch had a significantly shorter N1 latency ($M = 97.96,$
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36 $SE = 1.67$) than low pitch ($M = -104.04, SE = 1.29$). There was also a main effect of area,
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38 $F(2, 56) = 4.22, p = .020, \eta^2 = 0.13$, where N1 at F_4 was marginally significantly longer
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40 in latency ($M = 102.94, SE = 1.47$) than both F_z ($M = 100.60, SE = 1.52$), $p = 0.052$, and
41
42 F_3 ($M = 99.47, SE = 1.49$), $p = .05$. For N1 latency in the central region, there was a main
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44 effect of pitch, $F(1, 29) = 24.59, p = 0.000, \eta^2 = 0.46$. High pitch ($M = 96.97, SE = 1.48$)
45
46 had a significantly shorter N1 latency than low pitch ($M = 103.52, SE = 1.08$). There was
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48 also a main effect of area, $F(1.34, 38.98) = 4.66, p = 0.03, \eta^2 = 0.14$, where N1 at C_3 had
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50 a significantly shorter in latency ($M = 98.10, SE = 1.20$) than at C_z ($M = 100.77, SE =$
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52 1.24), $p = 0.02$. Lastly, there was a significant interaction of pitch and area, $F(2, 58) =$
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3 3.27, $p = .045$, $\eta^2 = 0.10$. For all areas, high pitch had a shorter latency than low pitch.
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5 Specifically, for C_3 , high pitch had a shorter N1 latency ($M = 95.48$, $SE = 1.37$) than low
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pitch ($M = 101.69$, $SE = 1.38$), $p = 0.00$. For C_z , high pitch had a shorter N1 latency ($M = 96.03$, $SE = 2.04$) than low pitch ($M = 105.48$, $SE = 1.22$), $p = .00$. For C_4 , high pitch had a shorter latency ($M = 99.69$, $SE = 1.79$) than low pitch ($M = 104.18$, $SE = 1.56$), $p = 0.01$.

In summary, for N1 amplitude, the frontal region showed a main effect of pitch, with low pitch having a significantly larger N1 amplitude than high pitch, whereas the central region showed a main effect of area, with N1 amplitude at C_z being larger than at C_3 . For N1 latency, both the frontal and central regions showed a main effect of pitch, with high pitch having a shorter N1 latency than low pitch (see Figures 4 -7). Again, nicotine did not affect N1 amplitude or latency.

P2: For P2 amplitude in the frontal region, there was a main effect of drug group, $F(1, 23) = 4.46$, $p = .046$, $\eta^2 = 0.16$. The nicotine group had a significantly larger P2 amplitude ($M = 1.68$, $SE = 0.25$) than the placebo group ($M = .97$, $SE = 0.23$). For the P2 amplitude in the central region, there was a main effect of pitch, $F(1, 28) = 10.46$, $p = .003$, $\eta^2 = 0.27$. High pitch had a significantly larger P2 amplitude ($M = 2.03$, $SE = 0.17$) than low pitch ($M = 1.62$, $SE = 0.15$). There was also a main effect of area, $F(1.49, 41.69) = 10.17$, $p = .001$, $\eta^2 = 0.27$, where P2 amplitude at C_3 ($M = 1.47$, $SE = 0.17$) was significantly smaller than at both C_z ($M = 2.07$, $SE = 0.17$), $p = 0.000$, and C_4 ($M = 1.94$, $SE = .16$), $p = 0.04$.

For P2 latency in the frontal region, there was a main effect of pitch, $F(1, 23) = 14.42$, $p = 0.01$, $\eta^2 = 0.39$, where high pitch had a significantly shorter P2 latency ($M = 168.49$, $SE = 3.43$) than low pitch ($M = 178.87$, $SE = 3.30$). For P2 latency in the central

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3 region there was a main effect of pitch, $F(1, 28) = 8.26, p = .008, \eta^2 = 0.23$, where high
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5 pitch also had a significantly shorter P2 latency ($M = 174.04, SE = 2.76$) than low pitch
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7 ($M = 180.39, SE = 2.35$).
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11 In summary, for P2 amplitude, the frontal region showed a main effect of drug
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13 group, with P2 amplitude being higher in the nicotine group for all conditions and areas
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15 compared to placebo (see Figures 4 - 7). The central region showed a main effect of pitch
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17 and area, with P2 amplitude being larger centrally during high pitch for both nicotine and
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19 placebo groups. For P2 latency, both the frontal and central regions showed a main effect
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21 of pitch, with high pitch having a shorter latency than low pitch for all areas.
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25 **N2:** For N2 amplitude in the frontal region, there was a main effect of area,
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27 $F(1.39, 24.93) = 6.69, p = 0.01, \eta^2 = 0.27$, where N2 amplitude at F_z was significantly
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29 larger ($M = -1.61, SE = 0.25$) than at F_4 ($M = -1.14, SE = 0.18$), $p = 0.00$. For N2
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31 amplitude in the central region, there was a main effect of area, $F(1.49, 40.30) = 10.08, p$
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33 $= 0.01, \eta^2 = 0.27$, where N2 amplitude at C_3 was significantly larger ($M = -0.40, SE =$
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35 0.11) that at both C_z ($M = -0.10, SE = 0.16$), $p = 0.02$, and C_4 ($M = -0.80, SE = 0.17$), $p =$
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37 0.01 .
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41 For N2 latency in the frontal region, there was a main effect of area, $F(2, 34) =$
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43 $3.36, p < 0.05, \eta^2 = 0.17$, where N2 latency at F_4 was significantly shorter ($M = 266.56,$
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45 $SE = 3.08$) that at F_z ($M = 272.41, SE = 3.64$), $p = 0.03$. For N2 latency in the central
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47 region there were no significant findings.
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51 In summary, for N2 amplitude, the frontal and central region both showed main
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53 effects of area. For N2 latency, only the frontal region showed a significant effect, with
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55 the latency at F_4 being significantly shorter (see Figures 4 -7). Again, nicotine did not
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3 affect N2 amplitude or latency.
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6 **Discussion**

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8 The present study was designed to explore the potential cognitive mechanisms behind the
9 co-consumption of nicotine and music. To this end, electrophysiological responses to
10 high pitch and low pitch auditory stimuli were compared in groups of non-smoking
11 participants receiving nicotine and placebo. The results indicate a relatively selective
12 effect of nicotine on one particular component of auditory perception (P2, see below).
13 However, effects of interest in relation to other aspects of auditory perception (P1, N1
14 and N2) were also noted within the task. These various components of auditory
15 perception will be considered in turn:
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27 **P1:** An increase in P1 amplitude as well as a decrease in P1 latency is thought to
28 be indicative of enhanced arousal, which leads to improved primary auditory pathway
29 transmission (Harkrider & Champlin, 2001; Le Houezec et al., 1994) and increased
30 sensitivity to sensory input (Knott, 1985b). However, although nicotine does increase
31 physiological (and self-reported) indices of arousal (Foulds et al., 1997), this was not
32 reflected in a change P1 amplitude or latency in the present study (although P1 amplitude
33 was higher overall in the midline areas of the frontal and central regions of the scalp - F_z
34 and C_z - consistent with previous research showing the auditory P1 to have maximal
35 amplitude over these areas; Key et al., 2005). Although some previous research has found
36 nicotine to increase P1 amplitude in smokers (Knott, 1985b) and non-smokers (Harkrider
37 & Champlin, 2001), the effect overall has been weak and inconsistent across studies
38 (Friedman & Meares, 1980). As a consequence, the present results and those of others
39 reinforce the idea that arousal can be subdivided (Stavarache et al., 2009), and suggest
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3 that nicotine-induced arousal does not affect auditory processing, and thereby as a
4 corollary auditory transmission, or sensitivity to auditory stimuli in non-smokers.
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8 **N1:** An increase in N1 amplitude is indicative of an enhancement of selective
9 attention (Hillyard et al., 1973), while a decrease in N1 latency is related to more efficient
10 information processing of stimuli (Domino & Kishimoto, 2002; Friedman et al., 1974a).
11
12 However, in common with other nicotine studies with non-smokers (Harkrider &
13 Champlin, 2001; Knott et al., 2009a; Knott et al., 2009b), nicotine did not affect the
14 amplitude or latency of N1 in the present study, suggesting that for non-smoking
15 populations, nicotine may not affect selective attention. That aside, pitch was shown to
16 affect N1 amplitude and latency. That is, low pitch sounds resulted in a larger N1
17 amplitude compared to high pitch sounds in the frontal area. This contrasts with previous
18 research showing N1 amplitude to increase for high pitch (Domino & Kishimoto, 2002)
19 and high intensity sounds (Knott, 1985b). However, the results of these previous studies
20 were observed with abstaining smokers, which suggests that non-smokers may react to
21 auditory stimuli differently to smokers. Furthermore, responses to high pitch sounds in
22 our non-smokers were found to have shorter N1 latencies compared to low pitch sounds
23 in both the frontal and central regions. Interestingly, a previous study has found a similar
24 result for abstaining smokers, but not for non-smokers (Domino & Kishimoto, 2002).
25
26 This suggests there to be a more efficient processing for high pitch sounds compared to
27 low-pitched sounds.
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31 **P2:** A decrease in P2 amplitude is related to habituation processes (Ritter et al.,
32 1968; Rust, 1977) and an enhanced ability to disengage from irrelevant stimuli (Knott,
33 1985a, 1989) indicative of more efficient processing (Domino & Kishimoto, 2002).
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3 Indeed, habituation can be considered an overlearning based on repetition that results in
4 an increase in processing efficiency (Baldeweg et al., 2006). Our finding of a nicotine-
5 induced increase in P2 amplitude in the frontal region suggests that in non-smokers
6 nicotine may cause a lack of habituation, resulting in non-smokers being less able to
7 adapt to repeated stimuli. In previous studies, P2 has been found to consistently decrease
8 as a result of nicotine in auditory tasks of selective attention in smokers (Friedman et al.,
9 1974a; Friedman et al., 1974b; Friedman and Meares, 1980).

10
11 In the central region, P2 amplitude was found to be larger for high pitch compared
12 to low-pitched stimuli. Harkrider and Champlin (2001) similarly found P2-N2 amplitude
13 to increase for non-smokers with high-intensity stimuli compared to low-intensity stimuli.
14 This suggests that high pitch sounds may be difficult to habituate to. High pitch sounds of
15 equivalent intensity are physiologically louder than low pitch sounds (Contours, 2003).
16 Knott (1985b) suggests that high intensity sounds may be difficult to ignore because they
17 override selective mechanisms. Hence, they may also override other attentional processes
18 as well, such as habituation, and therefore increase P2 amplitude.

19
20 For P2 latency, both the frontal and central regions showed a shorter latency for
21 high pitch compared to low pitch sounds. Similar findings were reported by Domino and
22 Kishimoto (2002), who found an increase in P2 amplitude as a result of irrelevant, high
23 pitch tones. These results may suggest that high pitch sounds are processed faster than
24 low pitch sounds, and therefore processed more efficiently.

25
26 With a lack of effect of nicotine on N1 amplitude, N1 latency, and P2 latency, and
27 with an increase in P2 amplitude in the frontal region, the results of this study contradict
28 the most consistent findings of past research, which is that nicotine enhances selective
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3 attention and habituation processes. Our results suggest that non-smokers experience no
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5 change in selective attention and experience decrements in stimulus filtering and
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7 habituation processes as a result of nicotine intake (although it has to be acknowledged
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9 that selective attention was not assessed directly). This discrepancy may relate to the
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11 different stimuli (complex tones of different pitch) employed in our study and earlier
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13 studies (pulses, clicks and pure tones). **Complex tones mimic natural sounds more closely**
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15 **and they are known to be processed differently at the neural level, as evidenced by**
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17 **electrophysiological and behavioural indices (Tervaniemi et al., 200a,b).** However,
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19 perhaps more likely is the possibility that the effects of nicotine on selective attention and
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21 habituation in previous studies are more a reflection of withdrawal reversal, which
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23 returns abstaining smokers' cognition to baseline, rather than genuine and absolute
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25 cognitive enhancement.
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32 **N2:** The N2 component is inversely related to arousal (Picton & Hillyard, 1974;
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34 Picton et al., 1974) and therefore is reduced during states of high activation (Knott, 1989).
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36 Perhaps not surprisingly, given the negative results for P1 (which is also affected by
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38 arousal), N2 component amplitude and latency were not affected by nicotine in the
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40 present study. This contrasts with studies by Friedman and Meares (1980), and Friedman,
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42 Goldberg, and colleagues (1974b), who report a nicotine-induced decrease in N2. Our
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44 findings however do accord with those of Knott (1985b) and Knott et al. (1995), both of
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46 whom used non-smokers, in contrast to Friedman and Meares (1980), and Friedman,
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48 Goldberg, and colleagues (1974b) who both used smokers. This pattern of results
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50 suggests that previously reported effects of nicotine on N2 may relate to the reversal of
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52 withdrawal effects.
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In conclusion, the results indicate a relatively selective effect of nicotine on one particular component of auditory perception, namely P2. The increase seen in P2 amplitude, indicating a decrease in habituation as a result of nicotine, suggests that people may smoke and listen to music at the same time because they do not experience a drop in emotional responses music when consuming nicotine. That is, music is repetitive by nature (Huron, 2006; Margulis, 2012) and past research has shown that familiarity with music, which is achieved through repetition, is a critical factor for emotional engagement with music (Pereira et al., 2011). Therefore, nicotine may help to stop smokers or other nicotine consumers from disengaging from music's repetitive elements by decreasing habituation. This in turn may lead to more emotional engagement with music during nicotine consumption. By decreasing adaptation, nicotine may extend the temporal window during which the listener is able to appreciate a piece of music rather than becoming bored with it.

Limitations and future research

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3 Although sound stimuli of different pitches (as used in the present study) incorporate a
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5 fundamental musical dimension, they are of course not music. A simple definition of
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7 music is difficult to achieve, however in addition to pitch, music also often contains
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9 rhythm and melody. These elements of music are extended in time and so are not suitable
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11 for investigation using an ERP paradigm. Future work could consider looking at
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13 responses to true musical excerpts - containing rhythm and melody - using fMRI, the
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15 signals for which evolve on a longer time scale than their electrophysiological correlates
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17 in the EEG.
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22 Cigarettes are falling out of fashion thanks to the popularized electronic cigarette
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24 (e-cigarette) (Loughead, 2015). E-cigarettes work by inhaling a heated liquid that usually
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26 contains nicotine and flavoring, as well as propylene glycol and glycerol (McRobbie et
27
28 al., 2014). In this case, future experiments may be interested in using this method of
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30 nicotine administration because it most accurately imitates the act of smoking a real
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32 cigarette. This would increase the ecological validity for nicotine studies using a
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34 cigarette-smoking population. Furthermore, the growing popularity of e-cigarettes means
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36 that there is a part of the smoking population using this method of delivery in everyday
37
38 life. For this reason, future experiments may also be interested in examining the cohort of
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40 smokers who use e-cigarettes compared to those who use tobacco products. E-cigarette
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42 users may respond differently to nicotine since e-cigarettes deliver the drug at a much
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44 slower and lower rate than regular cigarettes, which can result in lower absorption of the
45
46 drug (Farsalinos et al., 2014; Schroeder & Hoffman, 2014). This difference in delivery
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48 and absorption may lead to different cognitive and electrophysiological responses and
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50 may ultimately affect consumers' preferences for certain nicotine products.
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Finally, the present study was confined to non-smokers. It is likely that smokers would respond differently to nicotine than non-smokers, due (for example) to pharmacokinetic and pharmacodynamic tolerance (e.g. Porchet et al., 1988). Therefore, further research could consider a design that compares the effects of nicotine on auditory processing in smokers and non-smokers.

For Peer Review

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Figures

Figure 1: The experimental procedure. Subjects fixated a cross which was followed 200 ms later by a blank screen for 800 ms. After that, a tone was presented for 300 ms - either high pitch or low pitch - followed by another 800 ms of blank screen before the visual stimulus, consisting of an up arrow and a down arrow. If they heard a high pitch sound, they were to focus on the position of the up arrow. If the up arrow was positioned on the left-side of the image, then they were to press '1' on the keypad; if the up arrow was positioned on the right-side of the image, then they were to press '4'. Alternatively, if they heard a low pitch sound, they were to focus on the position of the down arrow. If the down arrow was positioned on the left-side of the image, then they were to press '1'; if the down arrow was positioned on the right side of the image, then they were to press '4'.

Figure 2: Channel/channel groups selected for analysis. A representation of the electrodes grouped together in the frontal region (upper circled channel groups) and central region (lower squared channel groups). These channel groups are further divided by hemisphere and midline. Their approximate locations corresponding to the 10-20 International System (Jasper, 1958) are labeled (e.g. F₃, F_z, F₄; C₃, C_z, C₄) next to each channel group.

Figure 3: Analysis montage showing waveform averages for the channels/channel groups used in analysis. The inner part of the figure (smaller waveforms) show the waveform averages for the different conditions at each of the relevant electrodes. Larger scale waveforms around the periphery show waveform averages for a representative from each channel group.

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3 Figure 4: Waveform averages for the six channels/channel groups used in the analysis. In
4 each case, the averages are shown separately for each condition (nicotine/placebo, high
5 pitch/low pitch). The ERP components interest (P1, N1, P2, N2) are also shown for each
6 channel/channel group.
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15 Figure 5: Amplitude (group mean values [mean \pm SE] in μ V) and latency (in
16 milliseconds; ms) of ERP peaks in the frontal region, for the nicotine and placebo groups
17 across the two pitch conditions (high and low). Note: P1, N1, P2, and N2 are ERP
18 components; F₃, F_z, F₄ are electrode groups
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27 Figure 6: Amplitude (group mean values [mean \pm SE] in μ V) and latency (in
28 milliseconds; ms) of ERP peaks in the central region, for the nicotine and placebo groups
29 across the two pitch conditions (high and low). Note: P1, N1, P2, and N2 are ERP
30 components; C₃, C_z, C₄ are electrode groups
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39 Figure 7: Topographic Event-Related Potential maps for the four components of interest
40 at peak amplitude. P1: Activation map captured at 46 ms for all pitch and drug
41 conditions; N1: Activation map captured at 101 ms for all pitch and drug conditions; P2:
42 Activation map captured at 175 ms for all pitch and drug conditions; N2: Activation map
43 captured at 275 ms for all pitch and drug conditions. All images are shown from an
44 overhead viewpoint.
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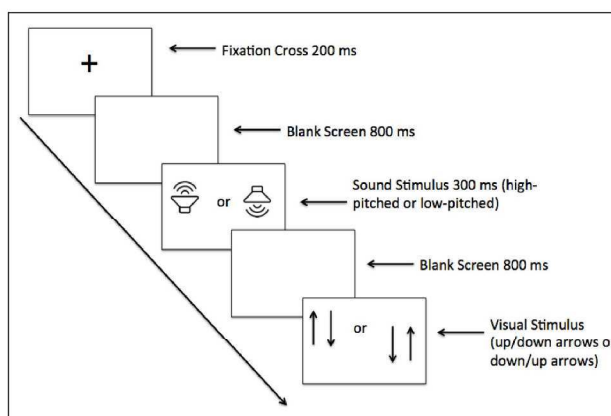


Figure 1: The experimental procedure. Subjects fixated a cross which was followed 200 ms later by a blank screen for 800 ms. After that, a tone was presented for 300 ms - either high pitch or low pitch - followed by another 800 ms of blank screen before the visual stimulus, consisting of an up arrow and a down arrow. If they heard a high pitch sound, they were to focus on the position of the up arrow. If the up arrow was positioned on the left-side of the image, then they were to press '1' on the keypad; if the up arrow was positioned on the right-side of the image, then they were to press '4'. Alternatively, if they heard a low pitch sound, they were to focus on the position of the down arrow. If the down arrow was positioned on the left-side of the image, then they were to press '1'; if the down arrow was positioned on the right side of the image, then they were to press '4'.

190x275mm (300 x 300 DPI)

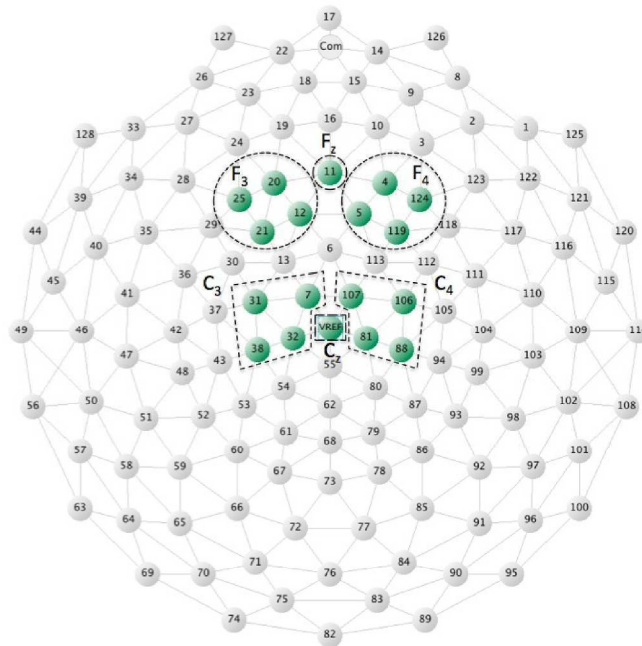


Figure 2: Channel/channel groups selected for analysis. A representation of the electrodes grouped together in the frontal region (upper circled channel groups) and central region (lower squared channel groups).

These channel groups are further divided by hemisphere and midline. Their approximate locations corresponding to the 10-20 International System (Jasper, 1958) are labeled (e.g. F3, Fz, F4; C3, Cz, C4) next to each channel group.

190x275mm (300 x 300 DPI)

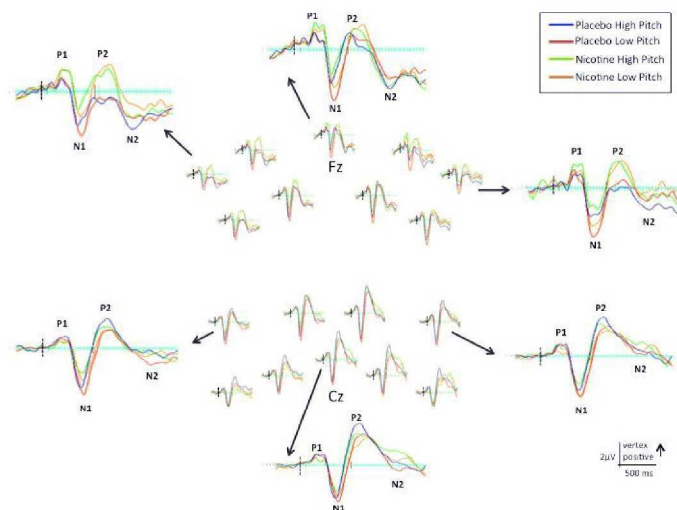


Figure 3: Analysis montage showing waveform averages for the channels/channel groups used in analysis. The inner part of the figure (smaller waveforms) show the waveform averages for the different conditions at each of the relevant electrodes. Larger scale waveforms around the periphery show waveform averages for a representative from each channel group.

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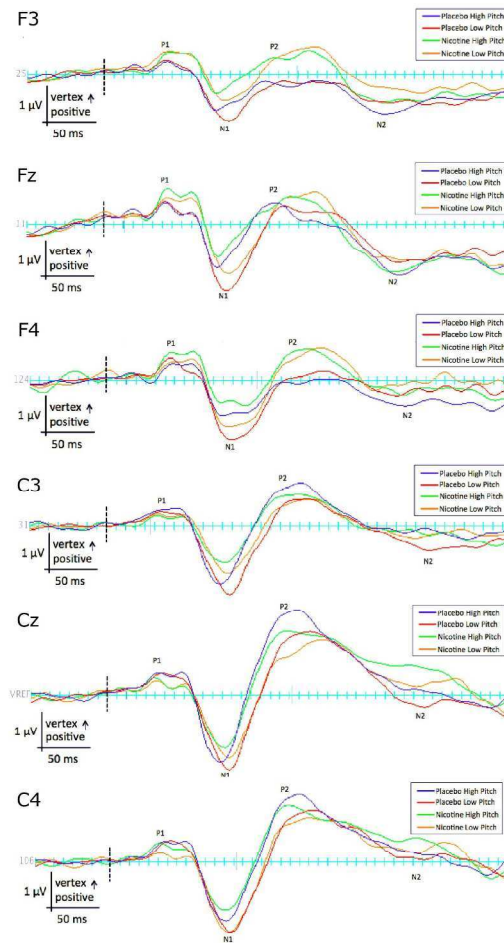


Figure 4: Waveform averages for the six channels/channel groups used in the analysis. In each case, the averages are shown separately for each condition (nicotine/placebo, high pitch/low pitch). The ERP components interest (P1, N1, P2, N2) are also shown for each channel/channel group.

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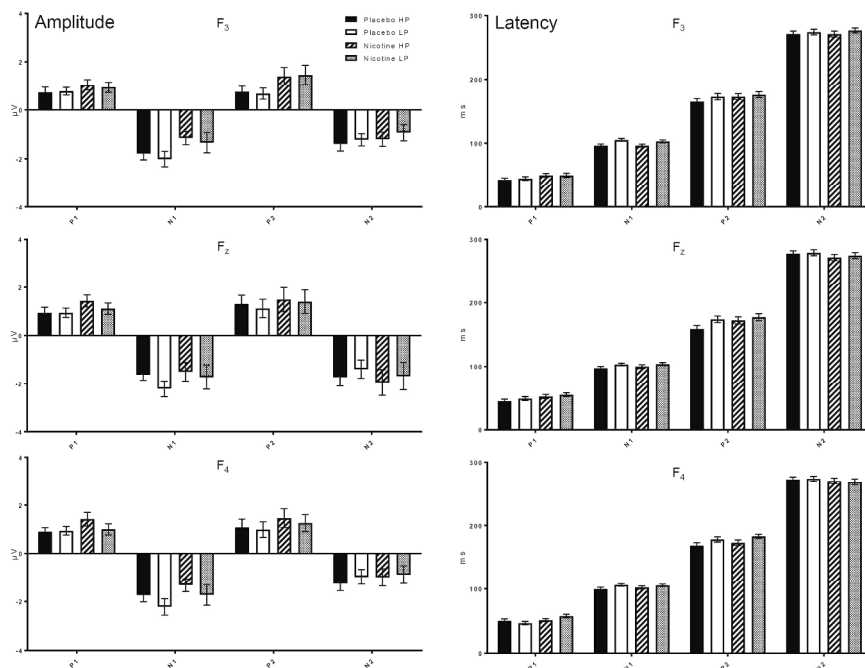


Figure 5: Amplitude (group mean values [mean ± SE] in µV) and latency (in milliseconds; ms) of ERP peaks in the frontal region, for the nicotine and placebo groups across the two pitch conditions (high and low). Note: P1, N1, P2, and N2 are ERP components; F3, Fz, F4 are electrode groups

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Review

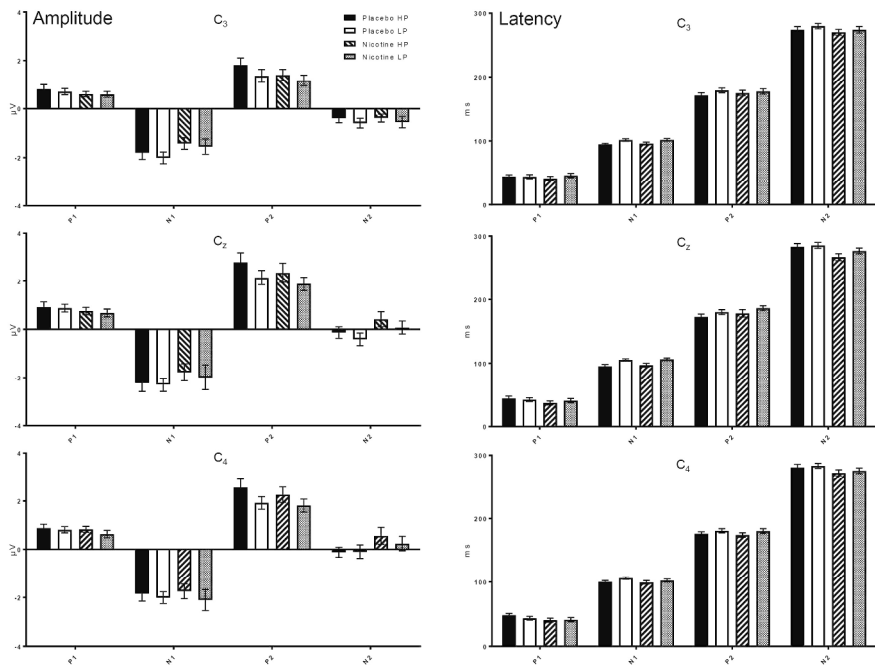


Figure 6: Amplitude (group mean values [mean ± SE] in µV) and latency (in milliseconds; ms) of ERP peaks in the central region, for the nicotine and placebo groups across the two pitch conditions (high and low). Note: P₁, N₁, P₂, and N₂ are ERP components; C₃, C_z, C₄ are electrode groups

275x190mm (300 x 300 DPI)

Review

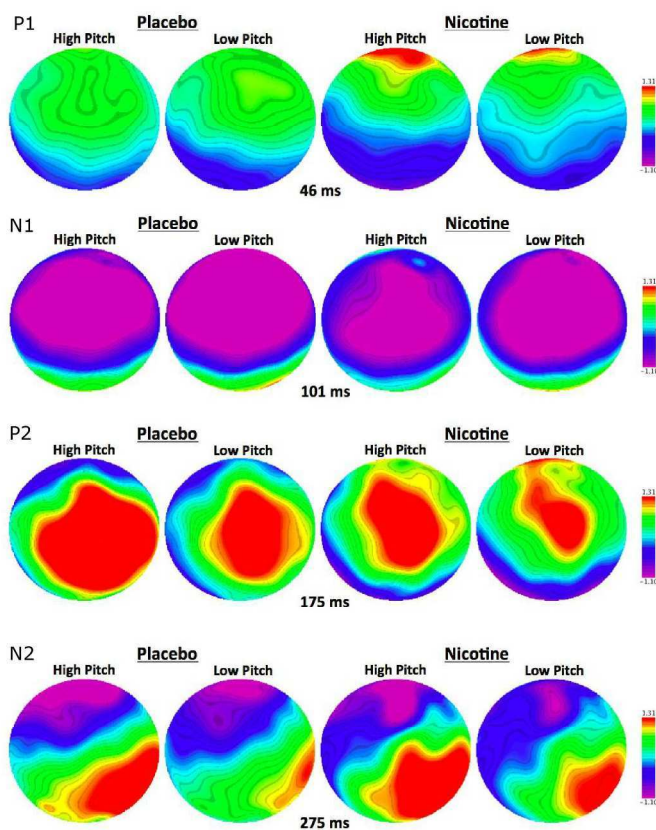


Figure 7: Topographic Event-Related Potential maps for the four components of interest at peak amplitude. P1: Activation map captured at 46 ms for all pitch and drug conditions; N1: Activation map captured at 101 ms for all pitch and drug conditions; P2: Activation map captured at 175 ms for all pitch and drug conditions; N2: Activation map captured at 275 ms for all pitch and drug conditions. All images are shown from an overhead viewpoint.

190x275mm (300 x 300 DPI)