Biological Psychology 154 (2020) 107907

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

The reward positivity: Comparing visual and auditory feedback

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ARTICLE INFO

Keywords:
Reward positivity
Doors task
ERP
EEG
Methods

ABSTRACT

Past work has demonstrated that the reward positivity (RewP) indexes a feedback-monitoring system sensitive to positive outcomes. Research on the RewP has frequently used simple guessing tasks. In the doors task, participants receive either feedback denoting monetary gain or loss on each trial after choosing one of two doors to "open." Typically, these tasks present visual stimuli on a computer monitor. The current study developed and validated a version of the doors task utilizing auditory stimuli to indicate gains and losses. Thirty-eight young adults completed both a standard visual doors task and a novel auditory doors task. Results indicated that the audio RewP was more positive and peaked earlier than the visual RewP. Additionally, the audio RewP both moderately correlated with and demonstrated similar internal consistency as the visual RewP. These results suggest that the auditory doors task elicits the same feedback-monitoring processes as the visual doors task.

1. Introduction

Feedback signaling the success or failure of actions is critical to goal pursuit. From this feedback, one can determine whether or not the desired reward has been obtained. One neural signature of feedback processing is the reward positivity (RewP), which is an event-related potential (ERP) that is maximal approximately 250 ms after reward compared to non-reward feedback at frontocentral electrode sites (Holroyd, Pakzad-Vaezi, & Krigolson, 2008; Proudfit, 2015). Whereas earlier studies referred to this ERP as the feedback-related negativity (Hajcak, Moser, Holroyd, & Simons, 2006), feedback negativity (Yeung, Holroyd, & Cohen, 2005), or feedback error-related negativity (Miltner, Braun, & Coles, 1997), more recent work suggests that this variability reflects a positive-going deflection that is reduced or absent on non-reward trials (Foti, Weinberg, Dien, & Hajcak, 2011; Krigolson, 2018). The RewP may reflect activation of the mesocorticolimbic dopamine system, a neural network related to reward processing (Carlson, Foti, Mujica-Parodi, Harmon-Jones, & Hajcak, 2011; Foti et al., 2011).

The RewP appears to be sensitive to a variety of environmental and individual differences factors. For example, past research has found that larger outcome magnitudes and decreased reward likelihood amplify the amplitude of the RewP (Novak & Foti, 2015; Sambrook & Goslin, 2015). Other research suggests that agency (Hassall, Hajcak, & Krigolson, 2019), the timing between an action and feedback (Weinberg, Luhmann, Bress, & Hajcak, 2012), and approach motivation (Threadgill & Gable, 2016, 2018; Weinberg, Riesel, & Proudfit, 2014) can impact the RewP. Furthermore, individuals with increased depression (Burani et al., 2019; Whitton et al., 2016), anhedonia (Ethridge, Sandre, Dirks, & Weinberg, 2018), and substance use disorder (Joyner et al., 2019) symptoms demonstrate a blunted RewP. Together, it appears that the amplitude of the RewP reflects a range of circumstantial and individual differences variables.

One popular task used to study the RewP across a variety of domains is a simple guessing task known as the doors task (Proudfit, 2015). In this task, participants are shown two doors, and told that behind one of the doors is a green "up" arrow, which denotes a monetary gain or win; behind the other door is a red "down" arrow, which denotes a monetary loss. Participants are told to attempt to guess which door hides the green "up" arrow, because this outcome results in a monetary gain—and to avoid choosing the door that hides the red "down" arrow because this outcome results in losing money. Participants are instructed to accumulate as much money as possible across a series of trials in this doors task. So that outcome type is not confounded by frequency, half of the trials result in a monetary gain and half of the trials result in a monetary loss. The RewP is typically quantified in terms of the difference between gains and losses.

To date, the RewP following monetary gains compared to losses has only been examined in the context of visual stimuli and feedback. This is in contrast to other paradigms that have examined feedback-related ERPs. For example, Miltner et al. (1997) developed a time estimation task where participants press a button when they thought 1 s had passed after the presentation of an auditory tone. Participants then received feedback indicating whether or not they had accurately estimated when one second had passed. Feedback was presented in three

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https://doi.org/10.1016/j.biopsycho.2020.107907
Received 15 November 2019; Received in revised form 6 April 2020; Accepted 19 May 2020
Available online 23 May 2020
0301-0511/ Published by Elsevier B.V.

different modalities: auditory (hearing various tones), visual (seeing the letters X and O), or somatosensory (feeling electrical stimulation of two different fingers). Results indicated that, even though there were slight differences in latency and amplitude between various conditions, all three feedback types elicited a relative positivity following positive compared to negative feedback. These data suggest that the RewP may reflect the activity of a relatively generic feedback monitoring system irrespective of a specific sensory modality.

The current study sought to build upon previous work by developing an auditory doors task. Our goal was to directly compare the RewP elicited by a novel auditory version of the doors task to the traditional visual version of the doors task, using a within-subject design. More specifically, we aimed to compare the timing, amplitude, and psychometric properties of the RewP. If the auditory RewP demonstrates comparable properties to the visual RewP, the auditory RewP paradigm could be used in research where visual stimuli may be unfeasible, such as in virtual reality environments or for use with mobile electroencephalography (EEG; Scanlon, Redman, Kuziek, & Mathewson, 2019).

To this end, we predicted that auditory feedback indicating reward would elicit a more positive-going ERP response than auditory feedback indicating loss. Furthermore, we predicted a positive correlation between the RewP elicited in an audio doors task and the RewP elicited by a visual doors task. Finally, to examine if the RewP elicited in an audio doors task exhibited the same psychometric properties as the RewP elicited in a visual doors task, we examined the internal consistency of the RewP using split-half reliability.

2. Methods

2.1. Participants

43 undergraduates from the psychology subject pool at Florida State University participated in exchange for partial for course credit. The sample was college-aged (23 female; M = 19.26, SD = 1.27). Data of five participants were excluded from further analysis due to poor EEG quality (i.e., greater than 25 % of segments rejected in at least one task), leaving a final sample of 38 participants. All participants provided written informed consent, and the research protocol was approved by the Institutional Review Board at Florida State University. All participants had normal or corrected-to-normal vision and reported no history of head trauma or neurological disease. Additionally, all participants reported being able to adequately hear the auditory stimuli in the audio doors task and see the visual stimuli in the visual doors task after completing practice trials.

2.2. EEG tasks

Using a within-subjects design, participants participated in both the visual doors task and the audio doors task (with order counterbalanced across participants). The duration of both tasks ranged between 5 and 8 min, depending on how long the participants took to make their decision and progress through breaks. All participants were paid their earnings at the end of the visit. All stimuli for both doors task can be found at https://osf.io/6zwqb/ (DOI: 10.17605/OSF.IO/6ZWQB).

2.2.1. The visual doors task

The visual doors task was administered using Presentation software (Neurobehavioral Systems, Inc., Albany CA), and was similar to versions used in previous studies in our laboratory (Proudfit, 2015). In the visual doors task, an image of two identical doors was presented on a computer screen. Participants were told that they would either win or lose money on each trial. The goal of each trial was to guess which door would result in monetary gain and accumulate as much money as possible. Since monetary losses are experienced as twice as valuable as monetary gains (Tversky & Kahneman, 1992), participants were told that they could either win $.50 or lose $.25 on each trial. The task consisted of 30 gain trials and 30 loss trials, presented in pseudo-random order.

On each trial, participants would first see a fixation cross for 500 ms. Next, an image of two identical doors was presented until participants made their selection by clicking either the left or right mouse button, followed by another fixation cross for 1000 ms. Then, participants were presented an upward green arrow or a downward red arrow indicating monetary gain or loss, respectively, for 2000 ms. Finally, a fixation cross was presented for 1500 ms, followed by the message, "Click For Next Round." This remained on the screen until the participant clicked either mouse button.

2.2.2. The audio doors task

In the audio doors task, auditory stimuli were developed based on the visual stimuli described above. Participants were given the same instructions as the standard visual doors task, with the exception that all stimuli were presented through earbuds. Participants were seated at a computer monitor viewing a blank screen throughout the entirety of the auditory task. The task consists of 30 gain trials and 30 loss trials, presented in pseudo-random order. Four practice trials were included before beginning the audio doors task.[1]

On each trial, participants would first hear a female say the phrase, "Choose a door," spoken in a plain, monotone voice. Next, participants made their selection by clicking either the left or right mouse button, which would elicit a "click" sound. Then, after 1000 ms, participants heard a "ding" or "fart" sound indicating monetary gain or loss, respectively. Finally, after 2000 ms, participants heard "Click for next trial" presented in the same voice previously used, and advanced to the next trial by clicking either mouse button.

2.3. EEG recording and processing

Continuous EEG was recorded using an elastic cap with ten actiCAP slim electrodes positioned in accordance with the 10/20 system (LiveAmp, Brain Products GmbH, Gilching, Germany). Electrode FCz served as the online recording reference, and a ground electrode was placed on the forehead at FPz. Two electrodes were placed on left (TP9) and right (TP10) mastoids. Electroculogram (EOG) was recorded using four electrodes: two placed approximately 1 cm above and below the left eye and two at the outer canthi of both eyes. The remaining two electrodes were placed on the scalp at Cz and Pz. The EEG signal was digitized at 500 Hz and band-passed filtered from 0.01 to 100 Hz. Impedances were kept below 25 kΩ.

EEG data were analyzed using BrainVision Analyzer, version 2.1 (Brain Products, Gilching, Germany). Data were re-referenced offline to the average of the left and right mastoids and band-pass filtered from 0.1 Hz to 30 Hz. Data were segmented into feedback-locked epochs from -200 to 1000 ms, with the 200 ms segment prior to feedback onset serving as the baseline. Ocular artifacts were corrected using the Gratton and colleagues' procedure (Gratton, Coles, & Donchin, 1983). Then, epochs containing a voltage greater than 50 μV between consecutive sample points, a 175 μV change within a 400 ms interval, or a change of less than 0.5 μV within a 100 ms interval were automatically rejected. Feedback ERPs were then averaged separately for gain and loss trials.

To quantify the RewP observed in the difference waveform, we subtracted the average ERP for loss trials from the average ERP for gain trials for each subject, separately for each task. The RewP elicited in the

[1] In these practice trials, audio stimuli were presented with their visual counterparts. This was done so that participants were able to understand which auditory stimuli represented which part of the traditional doors task (doors appearing, gain, loss, etc.). This only occurred in the practice trials. During the actual audio doors task, no visual stimuli were presented.

audio doors task appeared to peak earlier in the waveform than the RewP elicited in the visual doors task. Therefore, we then scored the most positive peak in a 150–400 ms window at Cz and extracted a 50 ms window centered around this peak. We refer to this as the area around the peak of the difference waveform, or the ΔRewP. Consistent with prior work (Levinson, Speed, Infantolino, & Hajcak, 2017), we used split-half reliability to measure the internal consistency of the ΔRewP by calculating the correlation between the average of the odd and even trials in both the audio and visual doors task, corrected using the Spearman-Brown prophecy formula (Nunnally, Bernstein, & Berge, 1967). Finally, because the RewP has been found to overlap with the P300 (Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003; Novak & Foti, 2015), we also examined the P300. The P300 was quantified as the average activity from 350 to 600 ms at Pz for all four conditions (i.e., audio gain, audio loss, visual gain, and visual loss).

All analyses were conducted using IBM SPSS 23 (SPSS Inc., Armonk, NY). To examine condition differences in the ΔRewP between the audio and visual doors task, we utilized a paired-samples *t*-test. Analysis of the P300 was conducted using a 2 (modality: audio vs. visual) x 2 (outcome: gain vs. loss) repeated-measures ANOVA.

3. Results

Means and standard deviations for all variables in both the audio and visual doors tasks are presented in Table 1. The ΔRewP for both the audio doors task and the visual doors task exhibited fair reliability (Spearman-Brown corrected split-half *r*s = .64 and .54, respectively; Steiger's Z indicated that internal consistency did not differ between the ΔRewP for the audio doors task and visual doors task, $Z = .62$, $p = .538$).

Consistent with the impression from Figs. 1 and 2 , a paired-samples *t*-test confirmed that the ΔRewP was larger in the audio doors task than during the visual doors task, $t(37) = 3.13$, $p = .003$, $d = 0.51$, 95% CI [.17, .87].[2] Furthermore, a dependent-sample *t*-test found that the latency of the ΔRewP was earlier in the audio than visual doors task, $t(37) = -8.08$, $p < .001$, $d = 1.76$ 95% CI [1.21, 2.38]. Finally, the ΔRewP exhibited a moderate correlation between the audio and visual doors tasks ($r(36) = .50$, $p = .001$).

A 2 (modality: audio vs. visual) x 2 (outcome: gain vs. loss) repeated-measures ANOVA examining the P300 indicated no overall differences across modality ($F(1, 34) = 0.77$, $p = .386$, $\eta_p^2 = .02$) or as a function of outcome ($F(1, 34) = 1.40$, $p = .245$, $\eta_p^2 = .04$). Furthermore, the interaction was not significant, $F(1, 34) = .42$, $p = .524$, $\eta_p^2 = .01$.

4. Discussion

The present study examined ERPs elicited by feedback indicating reward and non-reward in a novel audio version of the doors task, and compared these ERPs to those elicited during the traditional visual doors task. Participants completed both an auditory and visual version of the doors task, in counter-balanced order. Gain feedback elicited a relative positivity in both the audio and visual doors task. Indeed, difference-based measures of the RewP (i.e., gain minus loss difference scores and area around the peak of the difference waveform) were positively correlated across tasks, suggesting convergent validity of reward-related neural activity across audio and visual versions of the task. Moreover, we found equivalently high internal consistency for reward-related ERPs in both versions of the task. Together, these results suggest that the audio doors task and the visual doors task elicit a similar RewP that likely reflects the activity of a generic feedback monitoring system that spans across sensory modalities (Miltner et al., 1997).

[2] To further explore this relationship, we also conducted a 2 (modality: audio vs. visual) x 2 (outcome: gain vs. loss) repeated-measures ANOVA examining the RewP using the average amplitude from 200 − 300 ms at site Cz, which is where the area-around-the-peak measures determined the RewP was maximal. Results indicated that there was a significant effect of outcome, in that gains elicited a larger RewP than losses, $F(1, 34) = 82.37$, $p < .001$, $\eta_p^2 = .71$. However, there was not a significant effect of modality, $F(1, 34) = 0.00$, $p = .99$, $\eta_p^2 < .01$. Importantly, similar to the area-around-the-peak measure, the interaction was significant, $F(1, 34) = 12.06$, $p = .001$, $\eta_p^2 = .26$, such that gain trials were larger in the audio doors task than the visual doors task ($t(34) = 2.27$, $p = .030$), whereas loss trials did not differ between the two tasks ($t(34) = 1.70$, $p = .099$).

Table 1
Means & Standard Deviations for All Variables.

	Audio Doors Task	Visual Doors Task
RewP Area around Peak of Difference Wave		
Latency (ms)	230.69 (33.97)	281.94 (21.60)
ΔRewP (μV)	8.52 (5.64)	5.98 (3.97)
P300		
Gains (μV)	11.44 (7.15)	12.83 (6.60)
Losses (μV)	12.42 (6.88)	13.21 (6.85)

Note. Standard deviations are in parentheses.

Despite these similarities, the RewP elicited during the audio doors task peaked earlier than the RewP elicited during the visual doors task. Past research suggests that the timing of the RewP can be influenced by perceptual properties that make feedback discrimination easier (Liu & Gehring, 2009); because even relatively simple changes to feedback stimuli can alter the timing of the RewP, audio feedback may have been discriminated more rapidly than visual feedback. In addition, the RewP was larger in the audio than visual doors task. Insofar as the P300 was not larger in the audio version of the task, these data suggest a relatively specific potentiation of reward processing when feedback was delivered in the audio modality. Although speculative, it is possible that gain feedback in the audio task were more pleasant and rewarding. Alternatively, it might be the case that variability in the RewP in the audio doors reflects, to some degree, physical properties of the sounds themselves (e.g., loudness, length, etc.). Future studies might further test these competing hypotheses by examining self-report measures and by changing the audio stimuli in the task (i.e., by counter-balancing sound-feedback mappings across subjects).

The present results found that there were no differences in the P300 between feedback type or modality. This is similar to past research that has found a comparable P300 between standard audio and visual stimuli (Mazaheri & Picton, 2005).It seems likely that the P300 captured broad orienting and attentional processes that were comparable across all feedback (i.e., all events were of equivalent significance; Hajcak & Foti, 2020; Halgren, Marinkovic, & Chauvel, 1998).

The audio doors task is a new version of an experimental paradigm that has been used extensively in the basic and applied literatures. Because both the audio doors task and the visual doors task demonstrated similarly excellent psychometric properties—and insofar as reliability is a prerequisite for validity—it stands to reason that the audio doors task might be used to elicit a reliable and robust RewP for studying individual differences (Hajcak, Meyer, & Kotov, 2017). Furthermore, the RewP is often studied in the context of learning tasks (Baker & Holroyd, 2011; Nieuwenhuis, Holroyd, Mol, & Coles, 2004). Thus, the current results suggest that audio signals related to learning might similarly elicit a RewP.

The audio version of the doors task could also be used in novel environmental contexts in which the visual version would be impossible. For instance, the auditory doors task could be utilized within a virtual reality (VR) environment (Kozlov & Johansen, 2010). An example of this would be in the domain of emotion research. Presumably, one could assess reward-related neural activity as a function of different emotion-related manipulations in the VR environment. Additionally, the auditory doors task could also be utilized when using mobile EEG

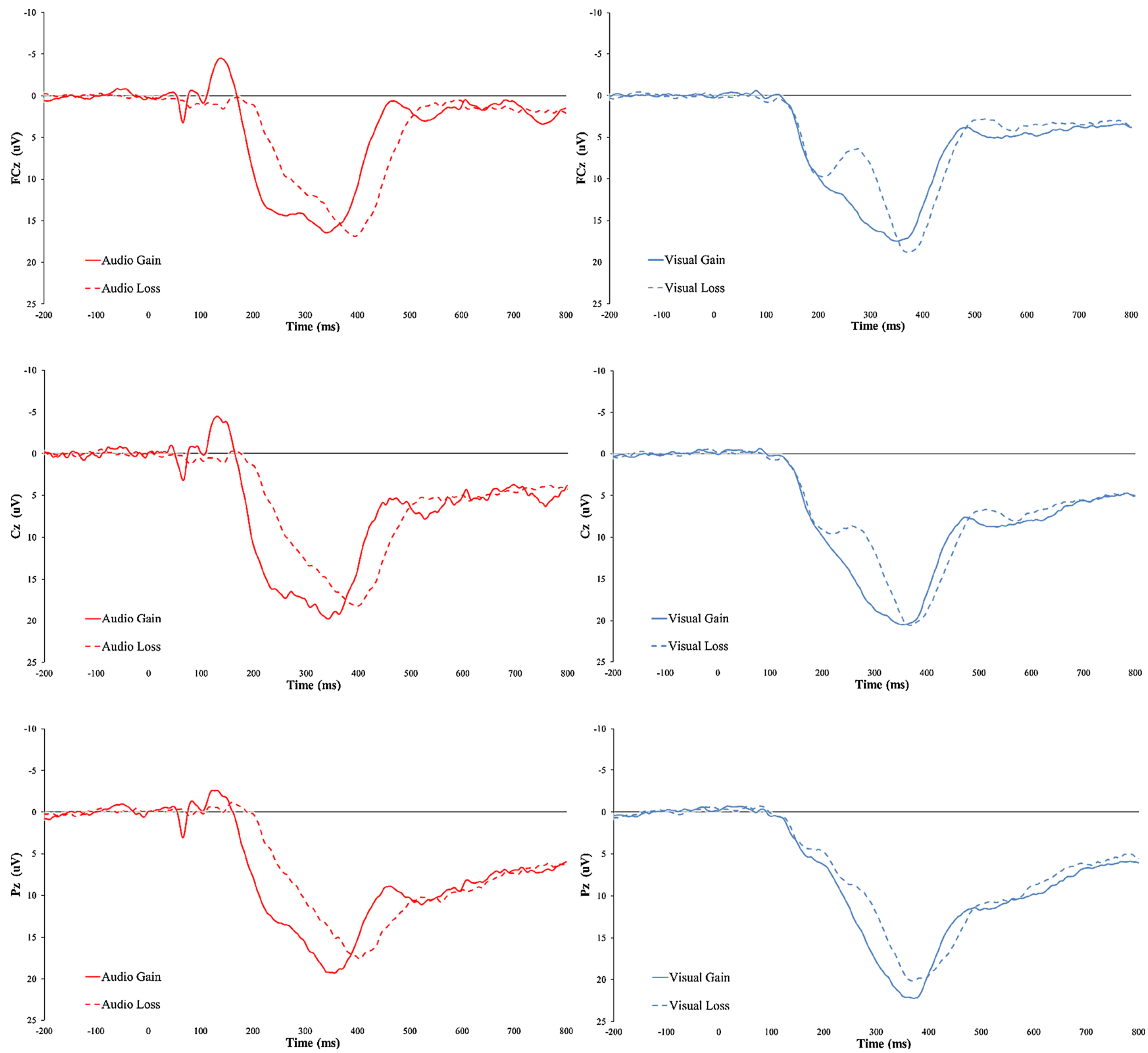

Fig. 1. Event-related potentials time-locked to the presentation of feedback (i.e., 0 ms) for gain and loss trials for both the audio doors task (left) and the visual doors task (right) at electrode FCz (top), Cz (middle), and Pz (bottom). Negative is plotted up.

systems (Scanlon et al., 2019). For example, past work has found that feedback processing extends beyond simple “good” vs. “bad” associations, but, rather, incorporates external error indicators to learn about the multiplex environments in which much of human behavior exists (Holroyd & Yeung, 2012; Sambrook & Goslin, 2015; Stahl, 2010). By integrating the auditory doors task and mobile EEG equipment that is quick to set up and relatively low in cost, researchers might be better able conduct field research, collecting reward-related neural activity in the “real world” (Krigolson, Williams, Norton, Hassall, & Colino, 2017). Thus, by utilizing an audio version of the doors task, researchers can increase the ecological validity of research by incorporating the complex settings in which individuals operate on a day-to-day basis.

Both the auditory and visual RewP were maximal at Cz along the midline – a scalp distribution consistent with previous studies on the traditional version of the doors task (Mulligan & Hajcak, 2018; Mulligan et al., 2018). Because the current experiment only utilized a small number of midline electrodes, we were limited in our ability to make topographical comparisons between the audio and visual RewP, and fully examine the scalp distribution of either RewP. Another limitation of the current experimentation is that we did not assess individual difference measures assessing constructs associated with the RewP, such as depression and substance abuse disorders. Future research should more fully investigate whether and how individual differences relate to the RewP in the audio version of the doors task.

Past research has often examined the RewP by utilizing simple visual guessing tasks, such as the doors task (Proudfit, 2015). The present experiment developed and tested a novel auditory version of the doors task. Relative to losses, feedback indicating monetary gain elicited an apparently similar positive deflection at Cz in both the auditory and visual versions of the doors tasks; these RewPs were correlated with one another and had comparable internal consistency reliability. The RewP was larger and peaked earlier, however, in the auditory version of the task. These data are consistent with previous studies that have found similar feedback-related ERPs across different modalities (Miltner et al., 1997), and further suggest that the RewP elicited during simple guessing tasks reflects a reward-related neural signal that is invariant with respect to feedback modality. Future studies might further evaluate the utility of the auditory doors task for studying individual differences, as well as in basic research and applied settings.

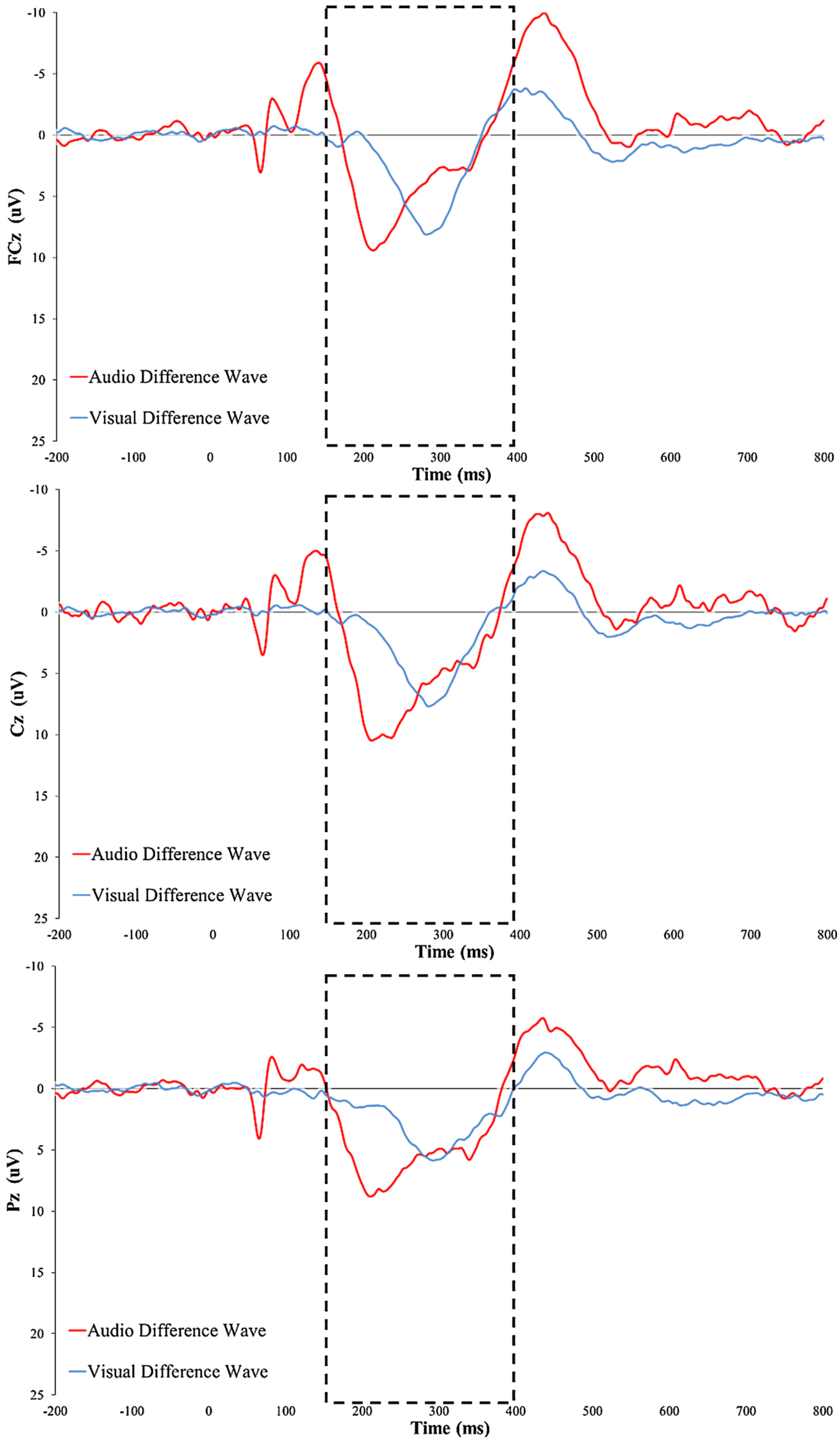

Fig. 2. Difference waveforms (win-loss) time-locked to the presentation of feedback (i.e., 0 ms) for both the audio doors task (red) and the visual doors task (blue) at electrode FCz (top), Cz (middle), and Pz (bottom). The time window (150-400 ms) where the peak amplitude of the difference wave was determined is outlined in a dashed-line black box. Negative is plotted up (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Open practices statement

The stimuli used for both the audio and visual doors task are available at https://osf.io/6zwqb/ (DOI: 10.17605/OSF.IO/6ZWQB). This experiment was not preregistered.

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