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The effect of task difficulty on feedback processing in children

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ABSTRACT

The study evaluated the effect of task difficulty on feedback processing as measured by the feedback related event related potentials (ERPs) in 7–11-years-old children. Children completed two declarative learning tasks that differed in the number of object-name pairs they were required to learn, deeming the task with twice as many pairs as more difficult. EEG was recorded during the tasks, and event related potentials time-locked to the feedback presentation were analyzed. Additionally, Accuracy was measured in test block at the end of each task. Behaviorally, children achieved better accuracy on the *easy* task than on the *difficult* task. In line with previous findings in adults, the FRN was not found sensitive to task difficulty. However, a feedback-related P300 and a fronto-central positivity that followed the FRN were found sensitive to task difficulty such that their amplitudes were larger in the *easy* task. This pattern is opposite to that reported previously in adults and may reflect the effect of motivation on attention allocation in children.

1. Introduction

School-age children are exposed to performance feedback daily and are expected to use such feedback to improve performance. The ability to monitor performance based on external feedback hinges on the intactness and maturation of the executive control system (e.g., Zelazo, 2015), and is supported by brain structures, known to undergo substantial structural and functional developmental changes during early and late childhood (Adleman et al., 2002; Benes et al., 1996; Casey et al., 1997; Cunningham et al., 2002; Ladouceur et al., 2004; Lambe et al., 2000; Rubia et al., 2007; Velanova et al., 2008). While the reliance on performance feedback for learning is an integral part of the schooling experience, it is unclear whether and in what way the difficulty level of learning tasks affects the processing of feedback by school-age children. Given that children, whose executive functions are still developing, are exposed to a learning environment with various levels of cognitive demands, it is important to understand whether such demands influence their ability to benefit from performance feedback. The goal of the present study was to examine feedback processing in children as they perform two learning tasks which vary in their level of difficulty.

The study of feedback-based learning in children has been enhanced by the examination of feedback related event related potentials (ERPs). The feedback related negativity (FRN) is a negative deflection in the averaged EEG time locked to the presentation of feedback stimuli. The FRN amplitude peaks at about 250–350 ms over fronto-central recording sites and is typically larger for negative than positive feedback (Miltner et al., 1997). Converging evidence points to the anterior cingulate cortex (ACC) as the generator of the FRN (e.g., Nieuwenhuis et al., 2004; Botvinick et al., 2001; Yeung et al., 2004). The FRN is triggered by the delivery of feedback in various learning (e.g., Arbel et al., 2013; Arbel et al., 2014; Ernst and Steinhauser, 2012; Krigolson et al., 2009; Luft, 2014; Pietschmann et al., 2008; Sailer et al., 2010; van der Helden et al., 2010) and gambling tasks (e.g., Goyer et al., 2008; Hajcak et al., 2007; Gehring and Willoughby, 2002). An alternative interpretation of what has become to be known as the FRN posits that this feedback-related activation is not a negativity but rather a positivity, namely the Reward Positivity (RewP), which is triggered by the processing of a reward or positive feedback, suppressed by losses or negative feedback and generated in the striatum (e.g., Foti et al., 2011; Kujawa et al., 2018). Although the FRN and RewP refer to the same observed ERP activation, the labeling is significant as it affects the discussion of the functional significance of the component. To avoid assumptions about the functional significance of this ERP component, activations associated with positive and negative feedback were measured separately rather than as a difference wave in the present study.

Two other ERP components have been identified as related to feedback processing, a frontocentral positivity (FCP) that follows the FRN, and the P300. The FCP, which is a positivity with a peak latency of about 350–450 ms over fronto-central recording sites, has been found sensitive to feedback valence (positive and negative) and learning outcomes in feedback-based learning tasks (Arbel et al., 2013; Ernst and Steinhauser, 2012). More specifically, in Arbel et al. (2013) the amplitude of the FCP was found to be larger following negative feedback

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when compared with positive feedback. Additionally, larger (more positive) FCP amplitude was found to be associated with learned items. While the neural substrate responsible for producing this fronto-central component has not been identified, its possible function has been conceptualized as the product of an orienting attentional process (Butterfield and Mangels, 2003; Anderson, 2002; Conklin et al., 2007; Ernst and Steinhauser, 2012; Romine and Reynolds, 2005); an interpretation that is consistent with that of the P3a (Polich, 2007), or Novelty P3 fronto-central component elicited by salient deviant stimuli (Spencer et al., 2001).

The P300 is a positivity that peaks at least 300 ms following a task relevant rare or significant event in the context of frequent events (Donchin and Coles, 1988). It has been found to be larger for positive feedback during the initial phase of learning, and to negative feedback at the later phase of learning (Arbel et al., 2013). The P300 is hypothesized to index the need to update the mental model or schema of a stimulus context triggered by incoming stimuli (Donchin, 1981; Donchin and Coles, 1988). This context updating theory led to the interpretation of the P300 as a measure of attentional processes called for when context updating is needed (Polich, 2007). The P300 and the fronto-central positivity (or P3a) have been found to differ in their sensitivity to feedback valence during learning, with the P300 amplitude being larger to positive feedback at the beginning of the learning process and to negative feedback at the end of the learning process, and the FCP amplitude to negative feedback showing an increase from the beginning to the end of the learning process, with no change to positive feedback (Kim and Arbel, 2019). The P300 and the FCP were also found to have a different spatial distribution and sensitivity to experimental manipulations in non-feedback-related studies. For example, using spatial-temporal principal component analysis (PCA), Spencer, Dien and Donchin demonstrated the sensitivity of the P300 to task-relevant rare events and the Novelty P3 (or P3a) to task irrelevant novel events (Spencer et al., 2001).

Evidence points to behavioral and neurophysiological differences between children and adults, and among children of different ages in the processing of performance feedback. When compared with young adults, children have been reported to rely more heavily and respond more strongly to external feedback (Eppinger et al., 2009; Hämmerer et al., 2010), to differentiate less between positive and negative feedback (Hämmerer et al., 2010; Mai et al., 2011; Zottoli and Grose-Fifer, 2012), and to be more susceptible to interference from uninformative (Crone et al., 2004) or deceptive feedback (Eppinger et al., 2009). Such differences are captured by the feedback related ERPs, in the form of larger FRN to feedback, smaller amplitude differences between positive and negative feedback, and no amplitude differences between informative and uninformative feedback. Differences between adults and children in feedback-based learning under varying learning conditions have been attributed to the developing executive functions in children (Eppinger et al., 2009; Van Duijvenvoorde et al., 2008). While variables associated with the feedback have been evaluated in children and adults, variables related to the learning environment and task demands have yet to be studied in children.

The effect of task difficulty on feedback processing, which is the focus of the reported study, has been evaluated in adults but has yet to be examined in children. Somon et al. (2019) studied the effect of task difficulty on error-related and feedback-related ERP components in adults, using a modified flanker task with feedback. In the *easy* task, a single arrow pointing to one of two directions was presented, while in the *difficult* task congruent and incongruent arrays of arrows typical to a flanker task were used. The results indicated no sensitivity of the FRN to task difficulty, and a larger P300 amplitude in the difficult task regardless of valence. The results were interpreted to suggest that the P300 rather than the FRN captures the enhanced processing of feedback associated with increased difficulty. The goal of the present study was to evaluate the effect of task difficulty on feedback processing in children. Results consistent with previous findings in adults (2019) will include no modulation of the FRN by task difficulty, and larger P300 to feedback under the difficult condition. In light of previous reports (Arbel et al., 2013), the FCP was hypothesized to be larger following negative feedback. Additionally, it was hypothesized that the FCP will be sensitive to task difficulty with greater activation following negative feedback under the difficult task, indicating that greater attention is allocated to negative feedback under more challenging conditions. A declarative learning task was used to examine the sensitivity of the FRN to task difficulty when the processing of feedback is critical for task performance and learning outcomes.

2. Methods

2.1. Participants

Eighty-two children (42 females, 40 males) between the ages of 7 and 11 ($M = 9.5$, $SD = 1.1$) participated in the experiment after obtaining signed parental consent. English was reported as the primary language for all participants, and none of the participants reported a history of learning or neurological disorders. Data of three participants who were classified as non-learners (accuracy level of less than 0.5 on the learning tasks) were excluded. The present study includes analysis performed on 79 participants (41 females, 38 males) between the ages of 7 to 11 years ($M = 9.5$, $SD = 1.1$). Participants were provided monetary compensation for participating in the study.

2.2. Procedure

The study entailed one laboratory visit which lasted about 2.5 h. During the lab visit, a 32-channel HydroCel net by Electrical Geodesics Inc. (EGI) was applied on the participant's head. Participants sat in front of a 24" monitor in a quiet room and were asked to complete two learning tasks on a computer by responding with a button press to visual stimuli presented on the screen and auditory stimuli presented through speakers. E-Prime (PST, Inc., Pittsburgh, PA) was employed to create the task, present the stimuli, and record responses.

2.3. Experimental task

In the *easy* version of the task, participants were tasked with learning the non-word names of 10 novel objects. In the *difficult* version of the task, participants were tasked with learning the non-word names of 20 novel objects. In both tasks learning occurred through trial-and-error guided by feedback in a two-choice paired association task. During each trial, participants were presented with photos of two novel objects presented on the computer monitor, and with a single name presented auditorily through speakers. The non-word names were presented auditorily rather than visually to avoid the possible influence of different reading experiences and levels. Participants were asked to press one of two buttons on a response box to select the novel object associated with the presented name (i.e., left button to select the object on the left; right button to select the object on the right). Pairs of photos were always presented together, and the location of each object on the screen (right or left) was randomized across trials. The participant's response was followed by visual performance feedback (three Xs for negative feedback; three √s for positive feedback) indicating the accuracy of the selection. During the first training block, all participants received positive and negative feedback at an equal probability to create a baseline error rate of 50% for all participants. The participants' responses during the initial block determined the pairing between objects and names, which remained constant throughout the task. Feedback was therefore consistent throughout the task. In each task, the set of objects (10 in the *easy* task, and 20 in the *difficult* task) was presented in a block design such that each pair of object and name was presented once in a block for a total of ten trials in each block in the *easy* task and twenty trials in each block in the *difficult* task. Each

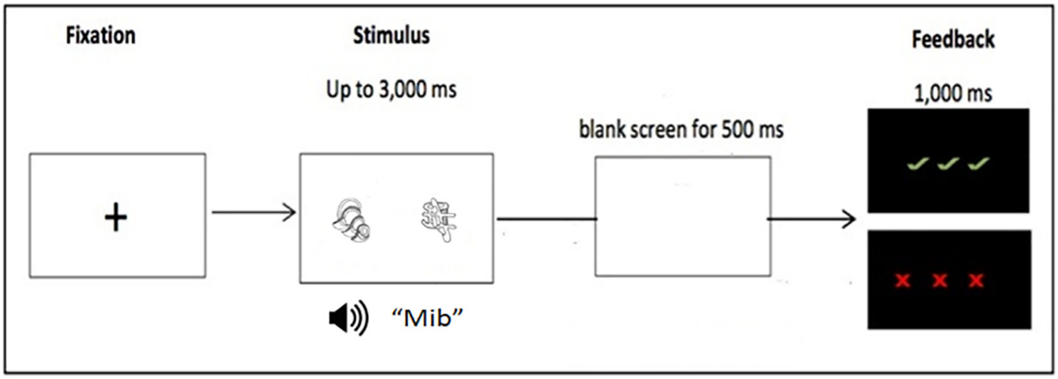

Fig. 1. An illustration of the sequence and time course of stimulus presentation followed by feedback.

participant was presented with a minimum of five and a maximum of twelve training blocks. Training was completed after a learning criterion of a cumulative accuracy of at least 90% was met. Accuracy calculation started on the fourth block. The training blocks were followed by a test block that presented the training items without providing performance feedback.

2.3.1. Trial structure

As illustrated in Fig. 1, a fixation cross appeared in the center of the screen for 500 ms followed by the visual presentation of two novel objects on the screen and an auditory presentation of a non-word name. Participants responded by pressing one of two keys to select one of the two objects to match the name. Participants were allotted 3000 ms to respond, after which three hyphens appeared in the middle of the screen to indicate that responses should be faster. The button press was followed by visual feedback presented on the screen for 1000 ms.

2.3.2. Stimuli

The images of the novel objects were derived from Kroll and Potter (1984). Non-words were generated from the ARC Non-word Database (Rastle et al., 2002).

2.4. EEG recording and analysis parameters

The 32-channel GES 400 System by Electrical Geodesics Inc. (EGI) was used to obtain dense-array EEG data using 32-channel HydroCel Geodesic sensor nets, comprised of Ag/AgCl electrodes attached to an elastic net following the international 10–20 system. Impedances were kept below 50 kΩ, which is appropriate for high input impedance amplifiers (Ferree et al., 2001). For analysis of the EEG recordings, 0.1 high-pass and 30 Hz low-pass offline filters were applied to the recorded data. EEG was time-locked to the onset of the feedback during the training phase of the tasks. Data were segmented into 1000 ms-long-epochs starting 200 ms before the presentation of the feedback and extending 800 ms after feedback presentation. With a sampling rate of 1000 Hz, each trial was consisted of 1000 time points. Baseline correction was performed on the segmented data, based on signal in the 200 ms preceding the feedback stimulus (i.e., −200–0 ms). Data were re-referenced to the average reference. Independent component analysis (ICA; Delorme et al., 2007) was conducted to identify and exclude factors that captured activation associated with eye movement and blinks. All participants had at least 20 artifact free segments per condition. Artifact free ERPs were averaged across trials under the two feedback and valence conditions, yielding categories in a 2 (*easy* task, and *difficult* task) by 2 (*positive feedback*, and *negative feedback*) structure. Each participant's data were processed and analyzed via the EGI Netstation, MATLAB R2015b (MathWorks, Natick, MA), and EEGLAB (Delorme and Makeig, 2004).

2.5. ERP analysis

Visual inspection of the topomap and the central electrodes determined that the FRN and FCP were maximal at the fronto-central electrode FCz, and that the P300 was maximal at the centro-parietal electrode Pz. To further analyze the ERP data, temporal principal component analysis (TPCA) was performed to disentangle ERP components that overlapped in time. This analysis was conducted using MATLAB scripts. TPCA for electrodes FCz and Pz resulted in seven temporal factors that accounted for 95% of the variance and retained for Promax rotation. Temporal factor 4 (TF4) with a maximal peak around 280 ms accounted for 9.8% of the variance and was identified as capturing the FRN activation. The fronto-central positivity (FCP) was depicted by temporal factor 3 (peak latency of ~380 ms; accounting for 12.6% of the variance), and the feedback-related P300 was captured by temporal factor 2 (peak latency of ~330 ms; accounting for 26.4% of the variance).

2.6. Statistical analysis

IBM SPSS Statistics 24.0 (IBM, Armonk, NY) was used to perform statistical analyses using the Greenhouse-Geisser correction for violations for sphericity (Greenhouse and Geisser, 1959). To analyze the behavioral data related to learning during the task, a repeated measures ANOVA was conducted with *Task Difficulty* (i.e., easy and difficult) as the independent variable and mean *accuracy* as the dependent variable. To analyze the ERP data, the factor scores that were the product of the temporal PCA were entered into repeated measures ANOVAs with *temporal Scores* as the dependent variable and *Task Difficulty* and *Feedback Valence* as within-subject factors.

3. Results

3.1. Behavioral data

On Average, participants completed 8.81 (SD = 2.2) blocks of trials on the *easy* task, and 9.06 (SD = 1.84) on the *difficult* task. Repeated measures ANOVA revealed no effect of task difficulty on number of blocks completed before reaching a learning criterion, F (1, 78) = 0.73, p = .39, η_p^2 = 0.009. Additionally, no differences in accuracy on the last block of the training phase were found between the two tasks across participants F (1, 78) = 0.99, p = .32, η_p^2 = 0.012. Accuracy data across training blocks under the two difficulty levels are presented in Table 1.

Participants' average accuracy on the test of the *easy* task was 0.93 (SD = 0.09), and 0.88 (SD = 0.13) on the *difficult* task. A repeated measure ANOVA with two levels of *task difficulty* was conducted. An effect of *task difficulty* was found, indicating better accuracy on the *easy* than the *difficult* task, F (1, 78) = 4.61, p = .03, η_p^2 = 0.05.

Table 1
Grand average accuracy (proportion correct) per block for each of the tasks.

Task difficulty		Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9	Block 10	Block 11	Block 12
Easy task	Avg.	0.50	0.59	0.63	0.72	0.81	0.80	0.81	0.87	0.86	0.87	0.93	0.95
	SD	0	0.12	0.14	0.13	0.11	0.14	0.14	0.11	0.13	0.11	0.04	0.05
Difficult task	Avg.	0.50	0.58	0.65	0.72	0.76	0.79	0.81	0.82	0.84	0.86	0.95	0.90
	SD	0	0.10	0.11	0.12	0.15	0.13	0.13	0.13	0.12	0.10	0	0

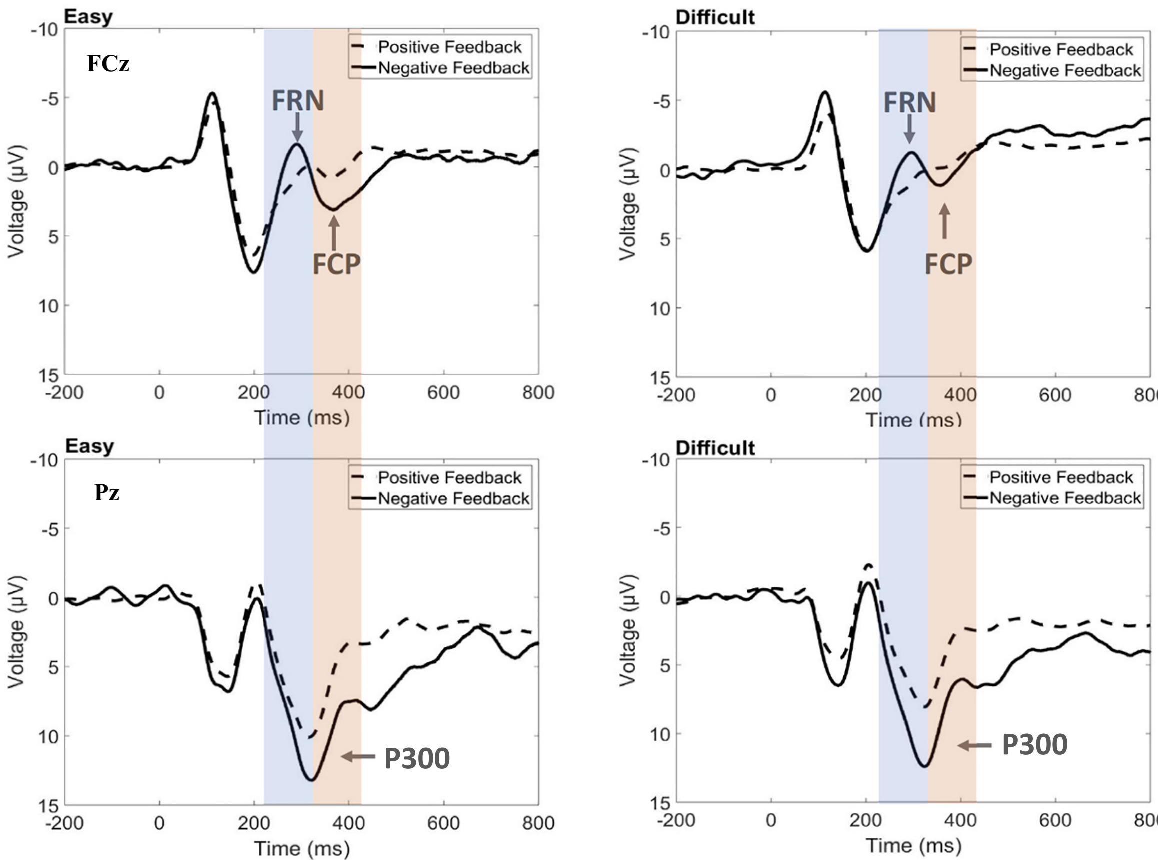

Fig. 2. Grand average event related potentials elicited by positive feedback (dashed line) and negative feedback (solid line) recorded in the fronto-central electrode (FCz; top), and in the centro-parietal electrode (Pz; bottom). ERPs elicited during the easy task are presented on the left; ERPs elicited during the difficult task are presented on the right.

3.2. ERP data

The grand averaged ERP data recorded from electrodes FCz and Pz and that capture the FRN, FCP and P300 under the two difficulty levels are presented in Fig. 2.

3.2.1. FRN

The amplitudes of the FRN (factor scores of TF4) for positive and negative feedback under the two difficulty levels are presented in Fig. 3. An effect of *Feedback Valence* was found $F\,(1, 78) = 15.1, p < .0001$, $\eta_p^2 = 0.16$, indicating that FRN to negative feedback was more negative than FRN to positive feedback. No effect of *Task Difficulty* $F\,(1, 78) = 0.41, p = .52, \eta_p^2 = 0.005$, or an interaction between *Feedback Valence* and *Task Difficulty* $F\,(1, 78) = 0.01, p = .9, \eta_p^2 = 0.0001$ were found. These results indicate that the FRN was not found sensitive to task difficulty.

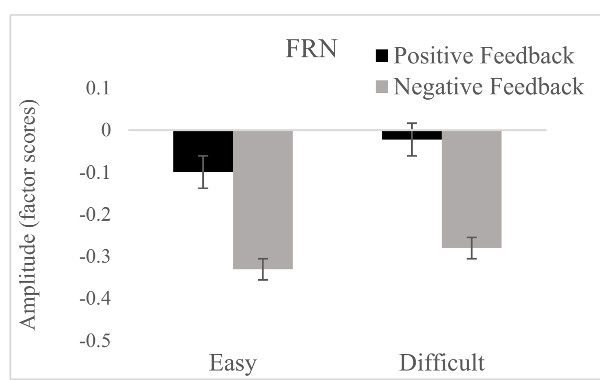

Fig. 3. Amplitude measure in PCA factor scores of the FRN elicited to positive (black bar) and negative (gray bar) feedback in the *easy* (on the left) and *difficult* (on the right) tasks.

3.2.2. FCP

The amplitudes of the FCP (factor scores of TF3) for positive and negative feedback under the two difficulty levels are presented in Fig. 4. An effect of *Feedback Valence* was found $F\,(1, 78) = 33.1, p < .0001$, $\eta_p^2 = 0.3$. indicating that FCP to negative feedback was more positive than FCP to positive feedback. An effect of *Task Difficulty* was found $F\,(1, 78) = 7.45, p = .008, \eta_p^2 = 0.09$, indicating that the FCP was larger

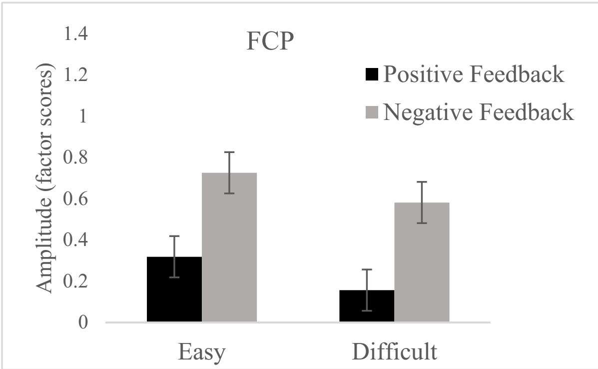

Fig. 4. Amplitude measure in PCA factor scores of the FCP elicited to positive (black bar) and negative (gray bar) feedback in the easy (on the left) and difficult (on the right) tasks.

(more positive) under the *easy task* condition. An interaction between *Feedback Valence* and *Task Difficulty* F (1, 78) = 7.2, p = .009, $\eta_p^2 = 0.08$, was also found. Post-hoc pairwise comparison indicated that differences associated with task difficulty were only present for negative feedback t (78) = −3.27, p = .002, but not for positive feedback t (78) = −0.954, p = .34. In summary, the FCP to negative feedback was found larger (more positive) under the easy task when compared with the difficult task.

3.2.3. P300

The amplitudes of the P300 (factor scores of TF2) for positive and negative feedback under the two difficulty levels are presented in Fig. 5. An effect of *Feedback Valence* was found F (1, 78) = 105.84, p < .0001, indicating that P300 to negative feedback was more positive than P300 to positive feedback. An effect of *Task Difficulty* was found F (1, 78) = 7.7, p = .007, indicating that the P300 was larger (more positive) under the *easy task* condition. No interaction between *Feedback Valence* and *Task Difficulty* was found, F (1, 78) = 0.1, p = .74. In summary, the P300 was found larger (more positive) after negative feedback in both tasks. It was overall larger, regardless of feedback valence, under the easy task when compared with the difficult task.

4. Discussion

The study was designed to evaluate the effect of task difficulty on feedback processing in children. Three ERP components that are associated with feedback processing have been measured in response to positive and negative feedback in two declarative learning tasks that varied in the number of pairs to be learned. In the *easy* task, participants were tasked with learning the non-word names of ten novel objects, while in the *difficult* task, the number of pairs was doubled to twenty pairs. Learning outcomes as measured by accuracy on a test immediately following the task were better in the *easy* task. In line with previous findings in adults, the FRN was not found sensitive to task difficulty in children. However, the FCP and P300 were found to be modulated by valence and task difficulty in a manner that was different from that previously reported in adults (Somon et al., 2019).

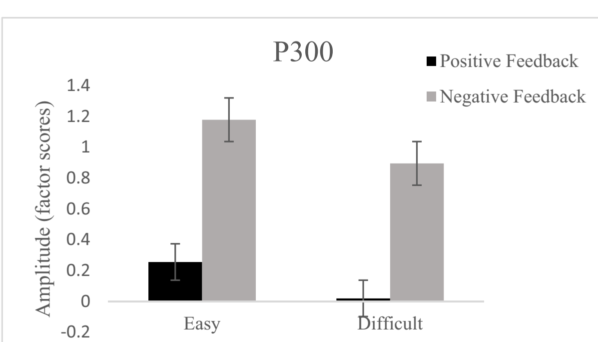

Fig. 5. Amplitude measure in PCA factor scores of the P300 elicited to positive (black bar) and negative (gray bar) feedback in the *easy* (on the left) and *difficult* (on the right) tasks.

4.1. FRN

The FRN was found sensitive to feedback valence such that negative feedback was associated with a larger amplitude. However, it was not found sensitive to task difficulty. These results are in line with those previously found in adults (Somon et al., 2019), although the nature of the task and the role of feedback in the two studies are different and therefore the ability to compare the two is limited. More specifically, feedback provided during the Flanker task employed by Somon et al. (2019) was evaluative but not informative, as task performance did not rely on the ability to extract information from feedback. In the declarative task of the current study, on the other hand, learning the correct pairing between a name and an object was guided by feedback. The lack of sensitivity of the FRN to task difficulty in the present study may imply that feedback under the two conditions (i.e., *easy* & *difficult*) was utilized to the same degree. It is possible that more substantial differences in task difficulty may have captured processing variations that were not observed in the current study. This suggestion is strengthened by the observation that although learning outcomes measured during a test block differed between the two conditions, no differences were found in the total number of blocks completed before reaching a learning criterion in the easy and difficult tasks. Alternatively, the FRN may reflect immediate processing of the feedback and therefore is more likely to be affected by the difficulty of extracting information from the feedback (i.e., when feedback is unclear or inconsistent), rather than the global difficulty level of the task. A support for this assertion is provided by findings that manipulating of the clarity of the feedback affected the amplitude of the FRN when other aspects of the task remained identical (Liu et al., 2014). An alternative account for the lack of FRN amplitude differences in the present study can be considered given previous findings that the FRN elicited in children did not show the same sensitivity to feedback inconsistency as shown in adults. More specifically, in Eppinger et al. (2009), children and adults who completed a probabilistic learning task were presented with feedback that was either consistently valid (provided the appropriate feedback 100% of the time) or inconsistently valid (provided the appropriate feedback 80% of the time, and the wrong feedback 20% of the time). While the FRN amplitude in adults was affected by the consistency of the feedback such that inconsistent feedback was associated with smaller FRN to negative feedback, in children, no differences were found between the two conditions. These findings were interpreted to suggest that learning interference affects children's ability to represent the correctness of a response. The results may also imply that children are more sensitive to the valence of the feedback than to the information it carries. However, the latter interpretation is challenged by evidence that negative feedback during the early stages of learning is associated with better learning outcomes than positive feedback in children (Verburg et al., 2019), suggesting that children are sensitive to the information feedback carries.

4.2. FCP & P300

Within the context of feedback processing in declarative learning tasks, the FCP and P300 have been discussed as reflecting an immediate post-feedback process to update working memory captured by the P300, and a slower attentional orienting process depicted by the FCP (Ernst and Steinhauser, 2012). In the present study, the amplitudes of these two components were found sensitive to feedback valence and task difficulty. Both components showed larger amplitude to negative feedback, and to feedback provided during the easy task. The sensitivity of the FCP to feedback valence has been reported in previous studies (e.g., Arbel et al., 2013; Arbel and Wu, 2016) with larger amplitude to negative feedback, suggesting greater attention triggered by the delivery of negative feedback. The amplitude of the feedback-related P300 has been reported to be sensitive to reward probability (Bellebaum and Daum, 2008; Bellebaum et al., 2010; Hajcak et al., 2007; van der Helden et al., 2010). In the context of a declarative task, Arbel et al. (2013) found that the amplitude of the P300 changed throughout the learning task, with larger P300 to positive feedback at the beginning of the learning process, and to negative feedback at a later phase of the learning task. These results were interpreted to reflect changes in levels of expectancy to positive and negative feedback during learning (e.g., Arbel et al., 2013). In the present study, the P300 was found larger to negative than positive feedback. These results can be explained based on the view of the P300 as reflecting expectancy level affected by subjective probability. Within this framework we suggest that negative feedback was less expected than positive feedback among children in our sample. It is important to note that in the present study learning was not divided into phases because of limited number of trials and therefore there was no evaluation of the P300 at different stages of the learning process. It is possible that the observed large P300 to negative feedback in the current study is the result of averaging trials with large P300 to positive feedback and trials with significantly larger P300 to negative feedback.

In the present study, the FCP and P300 were found sensitive to task difficulty. While the P300 amplitude was found to be overall smaller in the difficult task, regardless of valence, the FCP captured processing differences between the easy and difficult task that were specific to negative feedback. In adults, the P300 was found larger in a *difficult* task (Somon et al., 2019), leading the authors to suggest that feedback had a more important role under more difficult learning conditions. The opposite pattern of our results may imply that task difficulty affects processing among children in a different manner than in adults. More specifically, our results may suggest that children's attention to feedback is driven by motivation and success rather than by the need to allocate more resources to a more challenging task. In other words, it is possible that the larger FCP and P300 to feedback in the *easy* task reflects heightened attention to feedback under more favorable learning conditions. This interpretation is supported by previous findings that children's attention is affected by motivation (e.g., Chang and Burns, 2005). One may suggest that the reduction in P300 and FCP amplitudes under the *difficult* condition was due to fatigue associated with the difficult task. This alternative account is weakened by the lack of activation change in the FRN, and an overall similar accuracy rate across the blocks between the two tasks.

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Appendix A

Table 2 presents the results of a correlational analysis aimed at evaluating the possible correlation between the three feedback related ERP components. The results presented indicate that while moderate correlations were found within each component in response to different feedback valence (positive and negative) and experimental conditions (easy vs. difficult task), no significant correlations were detected between the ERP components.

Table 2
Correlations between the feedback-related ERP components under the two learning conditions.

Task difficulty:	Difficult		Easy		Difficult		Easy		Difficult		Easy	
ERP component:	FRN				FCP				P300			
Feedback valence:	Pos	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos	Neg
FRN D-PosFb	1	0.588**	0.525**	0.369**	−0.046	0.099	−0.090	0.091	−0.048	−0.052	−0.159	0.002
		0.000	0.000	0.001	0.682	0.378	0.427	0.424	0.670	0.641	0.158	0.987
FRN D-NegFb	0.588**	1	0.412**	0.400**	0.115	0.001	0.035	0.111	−0.028	0.017	0.015	0.069
	0.000		0.000	0.000	0.309	0.995	0.758	0.328	0.802	0.879	0.893	0.545
FRN E-PosFb	0.525**	0.412**	1	0.667**	−0.026	0.014	−0.163	0.013	−0.062	−0.086	−0.179	−0.002
	0.000	0.000		0.000	0.818	0.900	0.150	0.907	0.587	0.451	0.113	0.985
FRN E-NegFb	0.369**	0.400**	0.667**	1	0.093	0.049	0.046	0.006	−0.011	−0.011	−0.150	0.026
	0.001	0.000	0.000		0.414	0.667	0.684	0.959	0.923	0.924	0.184	0.817
FCP D-PosFb	−0.046	0.115	−0.026	0.093	1	0.552**	0.560**	0.313**	−0.106	0.026	0.048	0.114
	0.682	0.309	0.818	0.414		0.000	0.000	0.005	0.348	0.817	0.675	0.316
FCP D-NegFb	0.099	0.001	0.014	0.049	0.552**	1	0.465**	0.518**	−0.177	−0.085	−0.113	0.063
	0.378	0.995	0.900	0.667	0.000		0.000	0.000	0.111	0.447	0.320	0.581
FCP E-PosFb	−0.090	0.035	−0.163	0.046	0.560**	0.465**	1	0.579**	0.042	0.032	0.047	−0.099
	0.427	0.758	0.150	0.684	0.000	0.000		0.000	0.711	0.775	0.677	0.385
FCP E-NegFb	0.091	0.111	0.013	0.006	0.313**	0.518**	0.579**	1	0.064	0.186	0.079	0.008
	0.424	0.328	0.907	0.959	0.005	0.000	0.000		0.572	0.098	0.486	0.945
P300 D-PosFb	−0.048	−0.028	−0.062	−0.011	−0.106	−0.177	0.042	0.064	1	0.614**	0.514**	0.417**
	0.670	0.802	0.587	0.923	0.348	0.111	0.711	0.572		0.000	0.000	0.000
P300 D-NegFb	−0.052	0.017	−0.086	−0.011	0.026	−0.085	0.032	0.186	0.614**	1	0.452**	0.470**
	0.641	0.879	0.451	0.924	0.817	0.447	0.775	0.098	0.000		0.000	0.000
P300 E-PosFb	−0.159	0.015	−0.179	−0.150	0.048	−0.113	0.047	0.079	0.514**	0.452**	1	0.592**
	0.158	0.893	0.113	0.184	0.675	0.320	0.677	0.486	0.000	0.000		0.000
P300 E-NegFb	0.002	0.069	−0.002	0.026	0.114	0.063	−0.099	0.008	0.417**	0.470**	0.592**	1
	0.987	0.545	0.985	0.817	0.316	0.581	0.385	0.945	0.000	0.000	0.000	

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