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Feedback processing in children and adolescents: Is there a sensitivity for processing rewarding feedback?

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ABSTRACT

Developmental studies indicate that children rely more on external feedback than adults. Some of these studies claim that they additionally show higher sensitivity toward positive feedback, while others find they preferably use negative feedback for learning. However, these studies typically did not disentangle feedback valence and expectancy, which might contribute to the controversial results. The present study aimed at examining the neurophysiological correlates of feedback processing in children (8–10 years) and adolescents (12–14 years) in a time estimation paradigm that allows separating the contribution of valence and expectancy. Our results show that in the feedback-related negativity (FRN), an event-related potential (ERP) reflecting the fast initial processing of feedback stimuli, children and adolescents did not differentiate between unexpected positive and negative feedback. Thus, they did not show higher sensitivity to positive feedback. The FRN did also not differentiate between expected and unexpected feedback, as found for adults. In contrast, in a later processing stage mirrored in the P300 component of the ERP, children and adolescents processed the feedback's unexpectedness. Interestingly, adolescents with better behavioral adaptation (high-performers) also had a more frontal P300 expectancy effect. Thus, the recruitment of additional frontal brain regions might lead to better learning from feedback in adolescents.

1. Introduction

The ability to process external feedback is important in order to flexibly optimize our behavior, avoid harmful stimuli or situations, and seek out rewarding ones. It is especially important during development because children constantly encounter situations in their daily lives where they receive corrective feedback from parents or teachers. The ability to process and evaluate feedback develops during childhood and adolescence and is closely related to the maturation of the mediofrontal cortex, especially the anterior cingulate cortex (ACC), and the midbrain dopamine system (e.g., Casey et al., 2008; Fareri et al., 2008; Galvan, 2010; Hämmerer and Eppinger, 2012; Luciana et al., 2012; Somerville and Casey, 2010). It is not only crucial for the development of children's cognitive skills, e.g., their learning abilities, but also for self-regulation (e.g., Smith et al., 2013). However, the neuronal basis of feedback processing and its course of development are not yet well understood. An open question that is of high interest from a developmental as well as from an applied perspective is whether the sensitivity to positive and negative feedback is changing during childhood and adolescence. For instance, an increased responsiveness to positive, rewarding stimuli is often suggested to explain adolescent risk-taking (e.g., Casey et al., 2008; Ernst, 2014). The present study approaches this question by examining feedback processing after positive and negative feedback in children (8–10 years) and adolescents (12–14 years) by means of event-related potentials (ERPs).

Feedback processing can be examined online by means of the feedback-related negativity (FRN), an ERP component which is measured over fronto-central brain areas approximately 200–300 ms after subjects receive feedback and whose likely generator lies in the ACC (e.g., Gehring and Willoughby, 2002; Ferdinand and Opitz, 2014; Gehring et al., 2012; Holroyd and Coles, 2002; Miltner et al., 1997). It has been suggested that the FRN is elicited by decreases in dopamine activity when events occur that are classified as "worse than expected" and that its role is to train the ACC to adjust behavior (Holroyd and Coles, 2002). In line with this, studies show an FRN for negative feedback that increases with learning (e.g., Holroyd and Coles, 2002; Nieuwenhuis et al., 2002; Cohen et al., 2007; Opitz et al., 2011). However, recent findings indicate that positive feedback might also play a crucial role in behavioral adaptation and that it elicits a feedback positivity in the

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ERP (e.g., Eppinger et al., 2008; Holroyd et al., 2008; Potts et al., 2006). An alternative view proposes that the ACC is constantly predicting the likely outcomes of actions and signaling unexpected violations of these predictions (Alexander and Brown, 2011). Consistent with this, imaging studies have found larger ACC activation after unexpected events, signaling the need for increased control (Braver et al., 2001; Aarts et al., 2008; Jessup et al., 2010). There is currently no consensus about which aspects of the feedback, e.g., its valence or its unexpectedness, primarily drive learning. One reason for this discordance might be that as a consequence of the learning process, feedback valence and expectancy are oftentimes confounded. At the beginning of learning, positive and negative feedback should be equally unexpected. However, with the progress of learning, positive feedback will become more and more expected, while negative feedback will become unexpected. There are very few ERP studies that explicitly aimed at avoiding this confound during learning. They found that unexpected positive and unexpected negative feedback elicited an FRN in adult samples (Ferdinand et al., 2012; Oliveira et al., 2007).

To our knowledge there have been no similar attempts in developmental studies. However, the developing brain underlies a multitude of maturational changes which should, among other things, result in age-related changes in feedback processing well into early adulthood. According to recent developmental models, these changes should be particularly pronounced during adolescence, when an imbalance between brain systems responsible for cognitive control and those processing motivational or reward information results in mainly reward-driven behavior (e.g., Casey and Jones, 2010; Crone and Dahl, 2012; Ernst, 2014; Galvan, 2010). However, there are only a handful of electrophysiological studies examining feedback processing in children and adolescents to evaluate these theoretical considerations (for a review see Ferdinand and Kray (2014)). For example, it has been found that the FRN decreases with increasing age (Eppinger et al., 2009; Hämmerer et al., 2010; Zottoli and Grose-Fifer, 2012). This was interpreted as children showing a stronger reaction to external feedback as compared with adults, because external feedback plays a greater role in children's behavioral control while their internal control and monitoring processes are not yet fully developed (Crone et al., 2006). Additionally, relative to adolescents and younger adults, children's FRN amplitude usually differentiates less well between positive and negative feedback (Hämmerer et al., 2010; Mai et al., 2011; Zottoli and Grose-Fifer, 2012). This suggests that although they respond stronger to feedback in general, their monitoring system does not yet differentiate between these different outcomes. In line with the finding that children usually need longer to learn from feedback (e.g., Crone et al., 2006; Hämmerer et al., 2010), this indicates that they are less able to use the information conveyed by the feedback to change their behavior accordingly.

As for the question of whether children preferentially process positive or negative feedback, findings are less homogeneous. Eppinger et al. (2009) found a larger FRN after negative feedback for 10–12 year-old children as compared to young adults, whereas no age differences were obtained in the ERP after positive feedback in a probabilistic learning task. They inferred that children are more sensitive to negative feedback than adults. Similarly, Hämmerer et al. (2010) inferred a negativity bias in children's feedback processing because they showed less efficient behavioral adaptation after positive feedback (i.e., children showed more random behavior than adults). In contrast, Zottoli and Grose-Fifer (2012) compared feedback processing in adolescent (14–17 years) and young adult (22–26 years) males using a gambling task with unpredictable gains and losses. They found that the FRN in both age groups was larger for low than high gains, but this differentiation was not present for low and high losses. Although the authors suggested this might be due to the fact that their participants processed a low reward as a negative outcome, it could also hint towards a greater sensitivity or differentiation for rewards.

However, earlier studies are not well suited to answer the question of whether children preferentially process positive or negative feedback because the results are most probably influenced by differences in feedback expectancy (cf. Ferdinand et al., 2012). Earlier studies either used learning or gambling paradigms. Learning paradigms have the problem mentioned above that feedback expectancy and valence are confounded. In gambling, feedback is not behaviorally relevant and irrational expectancies (e.g., the gamblers' fallacy) can occur. Taken together, although models of brain maturation imply that the brain systems responsible for cognitive control and reward processing mature with different developmental trajectories, the respective impact of positive vs. negative feedback during learning and whether it changes during development is still an open question.

Therefore the goal of the present study was to examine the relative influence of valence and expectancy in feedback processing in children and adolescents using a paradigm including behaviorally-relevant feedback. For this purpose, we used a child-friendly version of a time estimation task in which positive and negative feedback were equally unexpected and were contrasted with expected feedback. This paradigm has proven useful in studies of adults by showing that positive and negative feedback can elicit a FRN of the same size when they are both unexpected (Ferdinand et al., 2012). Importantly, this FRN was larger than that after expected feedback (cf. Oliveira et al., 2007). Another finding of those studies was that unexpected positive feedback elicited a larger P300 than unexpected negative feedback, which was attributed to working memory updating after unexpected task-relevant events (for a review see Polich (2004, 2007)). It was concluded that in adults, the FRN is sensitive to learning-relevant expectancy violations and is not biased toward the processing of either positive or negative feedback. In contrast, the P300 is also sensitive to the feedback's valence.

In the present study, we were interested in whether children's and adolescents' ERPs would differentiate between positive and negative feedback if expectancy effects were kept equal between conditions. On the basis of earlier findings and the developmental considerations reported above, our hypotheses were that (a) children would have larger FRNs and (b) would show less differentiation between expected and unexpected feedback in their FRNs than adolescents. We also hypothesized that (c) adolescents would be more sensitive to positive feedback (in FRN and P300) because of an overactive reward system in combination with not yet fully developed cognitive control.

2. Material and methods

2.1. Participants

Twenty-three children (8–10 years) and 24 adolescents (12–14) took part in this study and received 24€ for their participation. Informed consent was signed by their legal guardians. All were healthy, right-handed, and had a normal or a corrected to normal vision. Three children were excluded, one because of motivational problems in sticking to the task and two because the adaptive mechanism did not succeed in generating the feedback frequencies as intended (trial numbers for negative feedback were 5 and 11, respectively). The effective sample consisted of 20 children (mean age$=$9.8 years, $SD$$=$0.8, 12 female) and 24 adolescents (mean age$=$13.5 years, $SD$$=$1.0, 14 female).

In order to assess the cognitive abilities of the two samples, all participants performed the Digit-Symbol Substitution Test (DSST; Wechsler, 2008) as a marker of perceptual speed, the Digit-Backwards Span Test (DBST; Wechsler, 2008) as a marker of working memory capacity, and a modified computer version of the Spot-a-Word Test (MWT-B, Lehrl, 1977) as a marker of verbal knowledge. In all tests, adolescents performed better than children (see Table 1) and all participants