International Journal of Psychophysiology 102 (2016) 33–46

Contents lists available at ScienceDirect

International Journal of Psychophysiology

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

Review

Performance monitoring in autism spectrum disorders: A systematic literature review of event-related potential studies

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ARTICLE INFO

Article history:
Received 29 January 2016
Received in revised form 9 March 2016
Accepted 10 March 2016
Available online 12 March 2016

Keywords:
Autism
Performance monitoring
Ne/ERN
FRN
Error positivity
ERP

ABSTRACT

Autism spectrum disorder (ASD) is marked by impairments in social–emotional situations, executive functioning, and behavioral regulation. These symptoms may be related to deficits in performance monitoring, i.e., the ability to observe and evaluate one's own behavior and performance which is necessary for the regulation of future behavior. The present literature review investigated electroencephalic correlates of performance monitoring in ASD. Event-related potentials (ERPs) considered in this review included internal performance monitoring components (error-related negativity, error positivity), external performance monitoring components (feedback-related negativity, feedback-P3), and observational performance monitoring components (observer error-related negativity, observer feedback-related negativity). The majority of studies point to reduced internal performance monitoring in ASD. External performance monitoring in reward-processing paradigms, where rewards are independent of performance, seems to be intact in ASD. So far, no studies have investigated the observer error-related negativity in ASD. Available data on the observer feedback-related negativity are inconclusive, since only two studies with differential study results investigated this construct in ASD. In general, results suggest that individuals with ASD have problems with internal performance monitoring and with learning from external, abstract feedback. In contrast, the processing of external, concrete feedback seems to be largely intact in ASD.

1. Introduction

Autism spectrum disorder (ASD) is a pervasive neurodevelopmental disorder characterized by qualitative impairments in social communication and interaction, along with restrictive and repetitive behaviors, interests, and activities (American Psychiatric Association, 2013). To date, knowledge of the etiology of ASD is limited. ASD is a heterogeneous disorder, often accompanied by comorbid disorders and with no single cause or biological marker that can account for the variety of symptoms associated with it (Happe et al., 2006). The core symptoms of ASD lie within the domain of social interaction and communication. It has been shown that individuals with ASD have deficits in empathy-related processes, such as inferring other people's emotional and mental states as well as in adequately responding to these states (e.g. Baron-Cohen et al., 1985). In addition, executive functioning (EF) is often impaired in ASD and may contribute to difficulties in everyday function in affected individuals (Eigsti, 2011). For example, deficits in cognitive flexibility and planning, has been demonstrated in a multitude of studies (see Hill, 2004; Russo et al., 2007 for reviews). One important aspect of EF is *performance monitoring*; the ability to observe and evaluate one's own behavior and performance necessary for regulating future behavior. Intact performance monitoring is integral to goal-directed and adaptive behavior. Previous studies suggest that performance monitoring may be altered in ASD, contributing to the social and cognitive deficits seen in individuals with ASD (Mundy, 2003). Therefore, the aim of the present literature review was to gain a better understanding of performance monitoring processes in ASD and their possible links to behavioral and cognitive symptoms associated with the disorder.

A better understanding of neurocognitive mechanisms associated with ASD may provide insight into inter-individual differences. Identifying where these differences exist is crucial for facilitating improved treatment options. It is therefore important to find ways for studying performance monitoring in ASD. Frequently utilized tools to study performance monitoring are electroencephalogram event-related potentials (ERPs; Falkenstein et al., 1990; Gehring et al., 1993; Miltner et al., 1997). As these neural indices appear to be particularly reliable in indexing performance monitoring processes (Olvet and Hajcak, 2009; Segalowitz et al., 2010), we reviewed studies utilizing electrophysiological means to study performance monitoring in ASD.

Performance monitoring involves the continuous tracking of ongoing actions and the detection of conflicting behavior or errors. Evaluating whether executed actions match intended outcomes is thus an essential part of performance monitoring; this function is referred to as *internal performance monitoring*. However, individuals may also monitor consequences of behavior, for example by considering feedback, in order to modify their behavior accordingly, which is called *external*

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http://dx.doi.org/10.1016/j.ijpsycho.2016.03.006
0167-8760/

performance monitoring. Another aspect of performance monitoring, the so-called *observational performance monitoring*, refers to the ability to use information gained from the observation of other individuals committing errors or receiving feedback on their actions in order to regulate one's own behavior.

An important neural source of performance monitoring is the anterior cingulate cortex (ACC) which appears to be implicated in all types of performance monitoring. For neurotypical (NT) adults, there is converging evidence that the same region of the ACC is implicated in internal- and external performance monitoring (Holroyd et al., 2004b) as well as in observational performance monitoring (Shane et al., 2008). Individuals with ASD often show abnormalities in the ACC (Haznedar et al., 2000; Mundy, 2003) and have difficulties in altering their behavior in response to environmental demands. For example, it has been shown that children with ASD have difficulties self-correcting their errors (Russell and Jarrold, 1998) and do not show post-error slowing in reaction time tasks as opposed to NTs (Bogte et al., 2007). Hence, these behavioral studies on performance monitoring and abnormalities in the ACC are indicative of potentially deficient performance monitoring in ASD.

It has been suggested that deficits in EF may contribute to the empathy related difficulties in ASD (Hughes and Russell, 1993; Ozonoff et al., 1991). Individuals with ASD have a reduced ability to act appropriately to socio-emotional stimuli and to use information about the mental states of others for guiding their own behavior, which may be explained by impairments in primarily cognitive empathy (Dziobek et al., 2008; Rogers et al., 2007; Schwenck et al., 2012). EFs are thought to facilitate these empathic processes (Decety and Meyer, 2008; Mahy et al., 2014). Indeed, higher levels of self-reported empathy have been found to be related to better internal performance monitoring in the general population (Larson et al., 2010). Cognitive aspects of empathy in particular seem to be related to performance monitoring (Larson et al., 2010), and deficits in cognitive empathy specifically are associated with ASD (Dziobek et al., 2008; Rogers et al., 2007; Rueda et al., 2015; Schwenck et al., 2012). Furthermore, the ACC is also central to empathy (Bernhardt and Singer, 2012). Thus, brain regions responsible for empathy and performance monitoring share a common neural structure, further suggesting a relationship between performance monitoring and empathy.

1.1. Performance monitoring components

ERP components are often used as indices of performance monitoring. One ERP component which has been linked to internal performance monitoring is the error-related negativity (ERN; also referred to as Ne), occurring 50–100 ms after error commission in cognitive performance paradigms (Falkenstein et al., 1990; Gehring et al., 1993). The ERN is often followed by a slow-going positive deflection, the error positivity (Pe), peaking at around 200–500 ms following an erroneous response (Falkenstein et al., 2000). Whereas the Pe seems to reflect the conscious recognition of an error, being only present when participants are aware of their errors, the ERN can also be observed when participants are unaware of their errors (Overbeek et al., 2005). In their review, Overbeek et al. (2005) identified further differences between the ERN and the Pe: while the Pe seems to be similar across different age groups, the ERN has been found to be smaller in children than in adults. Moreover, ERN, but not Pe, amplitude appears to be affected by medication use, while the Pe, but not the ERN, appears to differ across different cognitive paradigms. However, a recent study pointed out that different paradigms do demonstrate differences in ERN (and Pe) amplitudes, possibly related to task difficulty (Riesel et al., 2013).

In the context of external performance monitoring, the feedback-related negativity (FRN) has been mentioned. It is elicited by negative feedback and loss delivery in reward-processing paradigms and peaks at around 250 ms to 300 ms post-stimulus (Miltner et al., 1997; Gehring and Willoughby, 2002). The magnitude of gains and losses does not seem to influence FRN amplitude (Hajcak et al., 2006), reflecting a binary “good versus bad” evaluation of outcomes. The evaluation of “good versus bad” is however not based on the objective value of the outcome, but on its value relative to the value of remaining outcomes (Holroyd et al., 2004a). In relation to external performance monitoring, the feedback-P3 has also been mentioned, which peaks at around 300–600 ms post-stimulus (Goldstein et al., 2006). In contrast to the FRN, the feedback-P3 does seem to reflect objective magnitude of outcome, such that an increase in reward outcome is accompanied by an increase in P3 amplitude (Yeung and Sanfey, 2004).

Observing another person committing an error also elicits a negative-going ERP, the observer ERN (oERN), largest at around 230–250 ms post-stimulus with a pattern similar to the classic ERN (Carp et al., 2009; Miltner et al., 2003; van Schie et al., 2004). Likewise, an observer FRN (oFRN), with a pattern similar to the FRN is elicited when observing another person receiving negative feedback (Kang et al., 2010; Yu and Zhou, 2006).

Neural sources of the performance monitoring ERPs have been studied as well. The ERN, FRN, oERN and oFRN all seem to be generated by the ACC (Dehaene et al., 1994; Kang et al., 2010; van Schie et al., 2004). For the ERN and FRN, it has been proposed that the ERN and FRN are generated by phasic suppression of dopaminergic activity, conveying a reinforcement learning signal to the ACC, representing worse than expected outcomes (Holroyd and Coles, 2002). This may also hold for the oERN and the oFRN, given their common neural generator – the ACC – with the ERN and FRN. The ACC has also been mentioned to be the neural generator of the Pe. However, the exact neural source of the Pe is more difficult to determine and less well studied with inconsistent findings (Vocat et al., 2008; Herrmann et al., 2004; van Veen and Carter, 2002). To our knowledge, potential neural sources of the feedback-P3 have not been investigated yet. An overview of the described ERPs may be found in Table 1.

1.2. Aims and outline of the present literature review

The aim of the present review was to investigate electrophysiological correlates of performance monitoring in individuals with ASD. Additionally, we investigated whether particular characteristics of ASD are related to performance monitoring and whether aspects of empathy are related to ERP components indexing performance monitoring in ASD. Also, relationships were sought between performance monitoring and both ASD symptoms in specific and comorbid symptoms (e.g. internalizing problems) in general. In the Results section, findings regarding internal, external and observational performance monitoring components in ASD are presented. These findings are discussed in light of methodological and sampling differences between studies, such as the task paradigm used, quantification of ERP components or medication use. Furthermore, we examined the relationship between the presence of rewards and performance monitoring in ASD, as brain-imaging studies point to altered reward-processing in ASD (Delmonte et al., 2012; Dichter et al., 2012; Richey et al., 2014). It has been demonstrated that motivation affects performance monitoring in NT adults (e.g. Hajcak et al., 2005), and that the presence or absence of rewards may be an additional factor influencing performance monitoring (Ridderinkhof et al., 2004). In the context of external performance monitoring studies in particular, rewards appear to play an important role as performance feedback often indicates the gain or loss of reward in such studies (Hajcak et al., 2006). Based on the findings of the present review, hypotheses for future research are formulated.

2. Methods

Studies were searched from the databases PubMed and PsycInfo (last search was carried out on August, 23rd, 2015) using the search terms “autism” in combination with “*ERN*”, “*error negativity*”, “*error positivity*”, “*FRN*”, “*feedback negativity*”, or “*feedback positivity*”. Additional