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Experts in fast-ball sports reduce anticipation timing cost by developing inhibitory control

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ABSTRACT

The present study was conducted to examine the relationship between expertise in movement correction and rate of movement reprogramming within limited time periods, and to clarify the specific cognitive processes regarding superior reprogramming ability in experts. Event-related potentials (ERPs) were recorded in baseball experts ($n = 7$) and novices ($n = 7$) while they completed a predictive task. The task was to manually press a button to coincide with the arrival of a moving target. The target moved at a constant velocity, and its velocity was suddenly decreased in some trials. Under changed velocity conditions, the baseball experts showed significantly smaller timing errors and a higher rate of timing reprogramming than the novices. Moreover, ERPs in baseball experts revealed faster central negative deflection and augmented frontal positive deflection at 200 ms (N200) and 300 ms (Pd300) after target deceleration, respectively. Following this, peak latency of the next positive component in the central region (P300b) was delayed. The negative deflection at 200 ms, augmented frontal positive deflection, and late positive deflection at 300 ms have been interpreted as reflecting stimulus detection, motor inhibition, and stimulus–response translation processes. Taken together, these findings suggest that the experts have developed movement reprogramming to avoid anticipation cost, and this is characterized by quick detection of target velocity change, stronger inhibition of the planned, incorrect response, and update of the stimulus–response relationship in the changed environment.

1. Introduction

The capacity to anticipate future events is central to our ability to adapt to the environment, especially under severe time constraints. For instance, batters in fast-ball sports such as cricket or baseball have to execute their interceptive actions in less than half a second. Experts anticipate future events (i.e., when and where the ball will arrive) by extracting advance cue information from the opponent's movements before the ball is released, thereby circumventing the usual time constraints in information processing (Williams & Grant, 1999). Many traditional experiments using a precuing technique have confirmed that if a performer can anticipate a part of a future event (e.g., what kinds of stimuli are going to be presented and what kinds of responses will be required), the behavior becomes quicker, more stable and has a greater chance of being correct (e.g., Klemmer, 1956; Leonard, 1953, 1954; Rosenbaum, 1980, 1983; Zelaznik & Hahn, 1985). The central demands regarding perceptual and motor processing are reduced by attentional orientation, motor preparation, and a decrease in the number of stimulus–response alternatives in advance (Forster & Eimer, 2005; Leonard, 1953, 1954; Rosenbaum, 1980, 1983; Schmidt, 1968).

This anticipation benefit, however, becomes a cost when anticipation hinders the performer (LaBerge, 1973; Larish & Stelmach, 1982; Posner, 1980; Posner, Nissen, & Ogden, 1978). In a traditional experiment, Posner (1978) examined the relationship between cue validity and reaction times (RTs). He found that when advance cues have valid information for upcoming events, participants reduced their RTs (i.e., benefit) compared with the neutral condition (i.e., no advance information). In contrast, participants had longer RTs under invalid cue conditions that provided incorrect information about the stimuli. This anticipation cost, which has been observed in other paradigms (Larish & Stelmach, 1982; Posner, 1980; Schmidt & Gordon, 1977), resulted from biasing the preparation of an action in favor of one of several possible actions (Boulinguez & Nougier, 1999; Magill, 2011).

Moreover, the anticipation cost induced by motor preparation was seen to be present in a coincident timing task, which has severe time constraints. In this task, participants were asked to time their responses with the arrival of a moving target. Teixeira and colleagues (2006a) manipulates the displacement of a moving target. The target initially moved at a constant velocity, which was suddenly and unpredictably increased or decreased in some trials. In this task, if the participants executed the prepared response

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constructed by information about the initial target velocity before the change, large early or late timing errors occurred, depending on the direction of the velocity change. Teixeira and colleagues found that a low probability of target velocity change (i.e., a high probability of no velocity change) and/or insufficient time for correction led to unsuccessful movement timing correction (see also Teixeira, Lima, & Franzoni, 2005). Therefore, the results of Teixeira and colleagues suggest that motor preparation induced by the initial target velocity produces an anticipation cost under severe time constraints. However, Ripoll and Latiri (1997) reported that expert athletes in fast-ball sports did not significantly increase their timing errors in trials in which moving targets had unexpected velocity changes (see also Benguigui & Ripoll, 1998; Runigo, Benguigui, & Bardy, 2005). Several studies using other paradigms that induced motor preparation have shown reduced anticipation cost in expert athletes (e.g., Nougier & Rossi, 1999; Nougier, Stein, & Bonnel, 1991; Radlo, Janelle, Barba, & Frehlich, 2001). These results suggested that experts in fast-ball sports may develop some kind of cognitive process to circumvent the anticipation cost of the induced prepared response, but such cognitive processes are not well documented.

One possible reason for resistance in experts to the anticipation cost is their shorter visuomotor delay (VMD) in the time between visually registering information to produce an adjustment and the resulting observable movement events (Brenner, Smeets, & Lussanet, 1998; Carlton & Carlton, 1987; Lobjois, Benguigui, & Bertsch, 2005; Tresilian, 1993). Runigo and colleagues (2005) found that VMD is shorter in expert tennis players (162 ms) compared with novices (221 ms) (see also McLeod, 1987). It was concluded that this shorter VMD offers more time to adapt the interceptive movement to the changed environment and thereby improves the accuracy of the outcome (Runigo, Benguigui, & Bardy, 2010; Runigo et al., 2005). However, Teixeira and colleagues (2005) pointed out that even when the sign of movement adjustment is observed, it is not necessarily the case that adequate movement correction occurs in ordinary adults (see also Teixeira et al., 2006a). These investigators proposed that the rate of movement timing reprogramming (i.e., reprogramming from the prepared response constructed by the initial target velocity to a new adapted response for changed velocity) within given time periods is a critical factor for efficient movement correction. Consistent with this notion, RT costs observed during precuing tasks are attributed to time-consuming motor reprogramming processes occurring prior to the execution of the correct movement in invalid trials (Larish & Frekany, 1985; Lépine, Glencross, & Requin, 1989). It is assumed that experts' superior motor correction to avoid anticipation cost may be the result of the higher rate of movement timing reprogramming within given time periods. There has been no study, however, that has determined skill-related differences among varying rates of movement timing reprogramming.

The present study's first objective was to investigate whether experts in fast-ball sports exhibit a superior rate of movement reprogramming in coincident timing tasks with time pressure. This was accomplished by manipulating the time of arrival after velocity change (TAVC). A previous study revealed that movement reprogramming was difficult when TAVC was less than 300 ms (Teixeira et al., 2005, 2006a, 2006b). However, expert baseball batters who have had more training in time constrained tasks may be able to correct their movements more efficiently under these conditions by an improved visual search strategy (Bahill & LaRitz, 1984; Hubbard & Seng, 1954), movement kinematics (Matsuo, Kasai, & Asami, 1993; Matsuo & Kasai, 1994) and information usage (Delucia & Cochran, 1985). For these reasons, the present study set the TAVC from 100 ms to 300 ms to investigate the rate of timing reprogramming within severely limited time periods. If the experts can reprogram efficiently during limited time periods under changed velocity conditions, then their temporal accuracy should be similar to that observed when the target velocity is unchanged.

During the development of expert performance, there are functional and structural plastic changes in the brain (for review, see Nakata, Yoshie, Miura, & Kudo, 2010a). It has been hypothesized that the reprogramming process includes the motor inhibition of a prepared response (Neubert, Mars, Buch, Olivier, & Rushworth, 2010; Sharp et al., 2010) and re-specification for a new response (Larish & Stelmach, 1982; Leuthold & Jentzsch, 2002; Mars, Piekema, Coles, Hulstijn, & Toni, 2007). Therefore, these processes may have critical importance for development of expertise in movement correction. Because the motor reprogramming process is transient in nature (Leuthold & Jentzsch, 2002), capturing the neural correlates of the process necessitates the recording of brain signals with high temporal resolution. One method that perfectly matches this requirement is the recording of event-related potentials (ERPs). Although ERPs have not been thoroughly investigated with regard to motor reprogramming, Vidal and colleagues (1995) observed a negative and positive deflection after 200 ms and 300 ms, respectively. This is called the N200-P300a complex (i.e., negative and positive deflection after 200 or 300 ms, respectively, due to stimulus presentations) of ERP waveforms in the precuing task, which includes valid and invalid trials. Leuthold and Jentzsch (2002) also reported ERPs associated with motor reprogramming in a response priming task that revealed huge reaction time costs when validly prepared movements had to be reprogrammed after the imperative response signal. These authors found that reprogramming effects were reflected in ERP difference waveforms in terms of a centroparietally distributed negative and a frontal positive deviation. With respect to previous proposals of the motor reprogramming process (Larish & Stelmach, 1982; Mars et al., 2007), these ERPs have been interpreted as motor inhibition and/or re-specification processes. Moreover, in recent neuroimaging studies, the pre-supplementary motor area and the right inferior frontal gyrus were identified as crucial for the adaptation of actions to changes in the environment (Aron & Poldrack, 2006; Duann, Ide, Luo, & Li, 2009). These brain areas have often been implicated in motor inhibition processes (Aron & Poldrack, 2006; Aron, Robbins, & Poldrack, 2004; Forstmann et al., 2008; Hampshire, Chamberlan, Monti, Duncan, & Owen, 2010; Sharp et al., 2010) and organization of movement elements (Gerloff, Corwell, Chen, Hallett, & Cohen, 1997; Matsuzaka & Tanji, 1996; Shima, Mushiake, Saito, & Tanji, 1996). For these reasons, our second objective was to clarify specific cognitive activities associated with the higher rate of reprogramming in the experts by means of recording the ERPs. If baseball experts exhibit superior reprogramming, the ERPs associated with motor inhibition and/or re-specification (i.e., N200-P300a complex) may be more evident compared with the ERPs of novices. It follows that the cognitive strategy developed by experts in fast-ball sports to circumvent anticipation cost may have been induced by unexpected environmental changes.

2. Method

2.1. Participants

Fourteen male college students aged 18–23 years were enrolled in the study. All participants had normal or corrected-to-normal vision. Seven students were experts in fast-ball sports and belonged to the official college baseball team (with 7–12 years' experience in baseball). The seven expert players participated regularly in matches and generally spent 20 h/week in baseball training that included batting and fielding techniques in common baseball practice. The other subjects (the control group) were college students who played baseball but had not received any baseball-specific