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Timing accuracy in self-timed movements related to neural indicators of movement initiation

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Timely movement initiation is crucial in quick reactions or when a series of movements has to be strung together in a timed fashion to create a coordinated sequence. Stochastic neural variability can lead to misinitiation errors as reaction time studies suggest. Higher reaction times occur when preparatory neural activity reaches an initiation threshold later relative to shorter reaction times. Whether this also applies to self-timed movements is harder to scrutinize because they lack an external event that could serve as a reference for timing accuracy estimations. By example of a self-timed goal-oriented throwing task, we used a method that synchronizes the throwing movements by their kinematic profiles to assess relative timing differences in throwing release. We determined neural preparatory processes of the release using the movement-related electrophysiological Bereitschaftspotential (BP).

By analyzing differences in shape and timing of the BP in delayed and non-delayed throws, two variables could be extracted that are related to timing differences on the kinematic level. First, temporal deviations in BP curves partly meet the kinematic deviations. Second, delayed releases were preceded

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by a short flattening of the BP curves prior to release. Thus, temporal and shape deviations in the neural movement initiation are assumed to delay self-timed movements.

1. Introduction

Many motor tasks require that particular coordination patterns have to be appropriately timed either in reaction to external stimuli (reactive movements) or in relation to other movements (which we assign to self-timed movements). In both cases, at least two time points need to be related. In reactive movements, only the second point (the movement) can be controlled; the first is preset by the external stimulus. This applies to simple reactions like eye saccades or the first movement of a more complex reactive movement like catching or avoiding objects or obstacles. Self-timed movements, by our definition, represent movements whose varied aspects are temporally coupled in the absence of coupling to external events. Hence, both time points are specified by the performer himself. Goal oriented throwing, for instance, consists of two related actions: the arm movement accelerating the object to be thrown and the release of the object, usually executed by hand or finger opening. Both have to be accurately timed relative to each other in order to hit the goal.

The optimal relation between arm movement and release in throwing or similarly, the optimal time to react to an approaching object to be caught can be learned with practice. Throughout our lives we achieve to become fairly successful in throwing paper balls at waste bins, for instance. However, once in a while we fail. While some people would interpret this as misfortune, one can as well blame it to stochastic processes. Stochastic variations occur in all movement parameters, but especially release timing in throwing is prone to it. Since the time window for release is very short (e.g., 10–15 ms for dart throws; Hore, Watts, Martin, & Miller, 1995; Müller & Loosch, 1999), small deviations in release timing can cause the paper ball to miss the bin by centimeters. It has been suggested that behavioral variability can be accounted for by underlying neural stochastic variability in movement initiation (Hanes & Schall, 1996; Ivry & Spencer, 2004; Lee & Assad, 2003). On a neurophysiological level movement initiation is consistent with a rise of neural activity in motor areas of the brain. In terms of a so called accumulator model, the neural activity summates until a certain threshold is reached, which in turn leads to movement production. Fluctuations in activity accumulation give rise to different threshold passing times which then account for timing differences in starting the movement. This relation has already been confirmed for reactive movements (Cunnington, Iansek, & Bradshaw, 1999; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988; Hanes & Schall, 1996; Lecas, Requin, Anger, & Vitton, 1986; Rockstroh, Elbert, Lutzenberger, & Birbaumer, 1982; for review: Gold & Shadlen, 2007; Stuphorn & Schall, 2002).

However, there is no study to our knowledge addressing the relation between behavioral timing variability and neural initiation in self-timed movements. One reason for this might lie in the methodically difficult quantification of timing variability in behavioral or kinematic data due to a missing external temporal reference in self-timed movements or without clear starting or ending position that could also serve as reference. With this study, we present a possible solution of this problem: Timing is compared relatively between different trials as opposed to an absolute reference. We use a method that has previously been presented to assess differences in timing of throwing releases in self-timed throws (Pendt, Reuter, & Müller, 2011). Here, we combine this kinematic method with recordings of neurophysiological processes during preparation of movement. Our goal was to scrutinize whether timing variability on the kinematic level in a self-timed movement is reflected in changes in pre-motor neural activation similar to reactive movements.

As test movement, we chose the release movement in goal-oriented throwing. Here, timing has an essential influence on movement performance such that performers need to attach great importance