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Human Kinetics
RESPONSE

Reacting With or Without Detecting

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We begin our response by clarifying the concept of detection, and explaining why this is needed for initiating, but not for adjusting a movement. We present a simulation to illustrate this difference. Several commentators referred to studies with results that might seem in conflict with our proposal that movement adjustments have short latencies because there is no need to detect anything. In the last part of our response, we discuss how we interpret these studies as being in line with our proposal.

We would like to start our response by clarifying our definition of detection, as we understand from the comments that this was unclear. We consider detection to be distinguishing a signal from noise. The signal that we discussed in our opinion paper is a change in target position. Several commentators (Gielen, 2016; Cluff & Scott, 2016; Sainburg & Mutha, 2016) wondered whether our definition of detection is a conscious process or not. Let us reiterate what we stated in the opinion paper, “Detection generally leads to a conscious percept, but this percept is not necessary for a reaction to occur.”

One reason for the confusion about our use of detection is that generally various aspects of a signal are detected at the same time. For instance, to detect a change in target position, one also has to detect the presence of the target from the light falling on the retina (Reichenbach, 2016). The detection that we discussed in our opinion paper is the detection of a change in position, because we consider studies in which such a change drives the (slow) initiation or the (fast) adjustment of a movement. Several commentators argue that besides detection, a sensory decision is required (Chua et al., 2016; Franklin, 2016). We would prefer to formulate it differently: the essence of detection is that you decide whether something is a signal or noise, so the sensory decision is an integral part of detection.

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Now that we have clarified the concept of detection, we will discuss why we argue that it is needed for initiating, but not for adjusting a movement. To initiate a movement in response to a change in target location in a typical reaction time experiment, one has to set up a new control policy (Diedrichsen et al., 2010). A control policy is the set of rules (e.g., feedback control with a certain gain) to attain a certain goal given an estimate of the current state of the body and the target. Cluff and Scott (2016) argue that setting up a control policy also involves disengaging an ongoing postural control policy and that this might be the reason why initiating a movement takes more time than adjusting a movement. We agree, and point out that the switching between control policies is directly coupled to the detection of the change. We propose that the time delays do not mainly arise from switching policies, but from the fact that a change needs to be detected before the policy will be changed. The change does not need to be detected for constantly adjusting a movement to the changing estimate of target location that is used by the policy.

The notion that using a control policy that is based on continuously updating the estimate of the body and environment (i.e., feedback control) does not require any detection may sound counterintuitive: how can there be a response to a signal that is not detected? To illustrate the difference between a control policy that continuously updates the estimate of target location (for online movement adjustments), and a switch between policies based on the detection of a change (for movement initiation), we simulated the two responses for the same position signals (Figure 1). The signal that we modeled was a target that starts moving at 10 cm/s at t = 0. To mimic human sensory uncertainty, we added normally distributed measurement noise with a standard deviation of 0.5 cm to this signal. As a result of this noise, the sensed position is frequently moving in the opposite direction than the movement of the target. The control policy will make one follow the noisy signal (with a delay of 100 ms). It is not a problem to accidentally move in the wrong direction, as the noise will average out while continuously following the signal. The low-pass characteristics of the muscles will help in removing the noise. Note that this response is generated without any detection, as opposed to Reichenbach's claim that "online adjustments require change detection".

When analyzing experiments, one can easily determine the response latency of feedback control, either by averaging the responses over many trials (corresponding to the thick black curve in panel A) or based on more advanced analysis methods involving the complete response (Oostwoud Wijdenes et al., 2014). Such methods have also been applied to determine the latency of the vestibulo-ocular reflex, which uses feedback from the vestibular organ to control the direction of gaze. The resulting very short latency of this feedback control is 8.6 ms, which corresponds to the neural conduction time of the two-synapse pathway linking the vestibular organ to the eye muscles, and is not related to any decision process (Collewijn & Smeets, 2000). Note that this finding contradicts the suggestion in the commentary of Sainburg & Mutha that the vestibular-ocular reflex is "a clear example of a sensory detection–motor response." The latency of the visual feedback control of an arm movement of about 100 ms corresponds in a similar fashion to the neural conduction times of the pathway linking the retina to arm muscles.

One essential difference between using information to control an ongoing movement and responding to detecting a change by initiating a movement is that the latter involves a detection mechanism that needs to be reliable for every trial: there should be very few false alarms. Given the noisy nature of our sensors and neural processing, this is a serious problem. For the individual trials in Figure 1, the threshold for detecting a change in position must be well above the standard deviation of 0.5 cm to prevent false alarms or even responses in the opposite direction. In panel B, you see what happens if the threshold is set at three times the standard deviation of the noise. For the five example individual trials, this threshold will result in an additional delay of 50–140 ms before the target motion results in response initiation. In this example, the detection time is only determined by the speed of the change with respect to the noise. For the human nervous system, the time taken by neural processes will result in an additional component of the delay associated with the detection of a change.

We agree with Wyble & Rosenbaum (2016) that the most pressing question is why normal reaction times are so long. Reaction times of about 200 ms imply that detection (including any decision that needs to be made) takes about 100 ms. In our

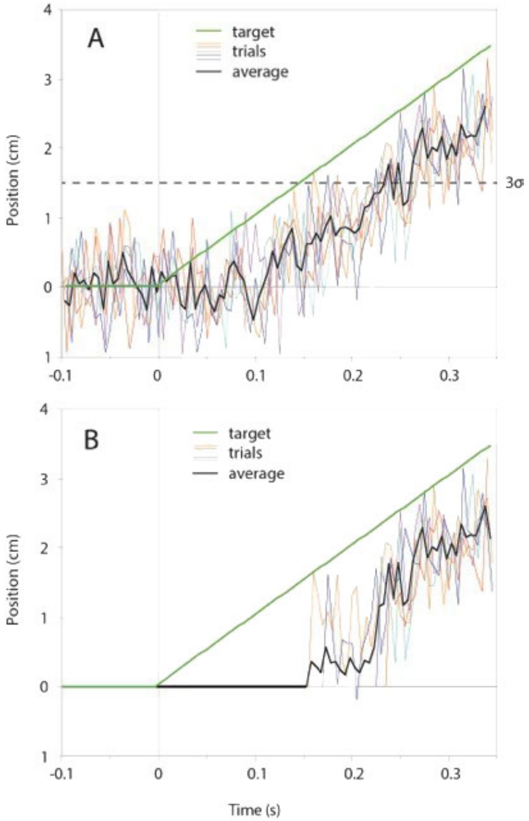

Figure 1 — Five example responses to a noisy (σ = 0.5 cm) position signal about a target that starts moving at 10 cm/s at time zero. **A** Response of a feedback system with a delay of 0.1s. **B** Response of a system that only starts responding to the noisy signal when it has detected the target's motion (threshold of 1.5 cm, indicated by the dashed line in A; same 0.1s delay).

opinion paper, we mentioned one study in which a shorter time was reported: 160 ms for detecting a rotation and selecting new grasping points if the direction of the rotation provided reason to do so (Voudouris et al., 2013), implying that detection only takes about 60 ms. Reichenbach (2016) discussed another paper that showed responses that involved detection with a latency of about 160 ms (Perfiliev et al., 2010). In that experiment, subjects were looking at a stationary ball, and were instructed to catch it as soon as it started moving. This task involved a selection, namely which hand to use. Why the detection takes about 60 ms in these tasks and about 100 ms in most other tasks is unclear to us.

In two commentaries (Chua et al., 2016; Sainburg & Mutha, 2016), the fast responses are compared with the startle-effect. The reduction of reaction times when a startling stimulus is presented together with the target stimulus (whereby the reduction in reaction time is larger than can be expected on the basis of sensory integration) has frequently been interpreted as the release of a prepared movement. However, a startling stimulus can reduce choice reaction times by the same amount as it does simple reaction times (Nijhuis et al., 2007; Reynolds & Day, 2007). Therefore, it is probably more appropriate to discuss the startle effect in terms of the detection stage (the startling stimulus somehow makes detection easier) than to argue that "short-latency visuomotor responses occur from … startle like mechanisms".

In the opinion paper, we compared fast movement corrections to express saccades. Gielen (2016) discusses the neural circuitry underlying the generation of express saccades. He argues that express saccades are generated faster than normal saccades because the former lack cortical involvement. According to the literature he cites, in normal saccades the cortical involvement is related to target selection, based on the detection of a new target. Both detection and selection of the target are needed when an initial fixation point and a target position are simultaneously present. To get an express saccade, one needs to remove the fixation point 100 ms before the target is presented. In this case, no selection (and thus no detection) of the target is required. This supports our suggestion that express saccades are so fast because the stage of detection is circumvented.

Blouin discusses data he collected which seems to indicate that the presence of short latency corrections depends on whether movement amplitude is a task constraint. He finds that corrections of movement direction were much smaller if movement amplitude was constrained (Sarlegna & Blouin, 2010). On the other hand, other experiments have reported short latency directional adjustments while movement amplitude was constrained (e.g., Brenner & Smeets, 1997; Veerman et al., 2008; Oostwoud Wijdenes et al., 2013). A possible reason for this difference might be in the control policy that is set-up when starting a movement, i.e., in the feedback-gain specified for responses to perturbations (as argued by Franklin, 2016). A high gain will result in responses that are clearly visible, but also in oscillations in the absence of damping. Therefore, if the damping is low and endpoint precision is required, the feedback gain cannot be very large and the counteraction of perturbations will be limited. If precision requirements are relaxed (e.g., if amplitude is irrelevant), the gain can increase, resulting in better counteracting of perturbations. Damping is much lower when the target is a virtual position in space (Sarlegna & Blouin, 2010), than when it is a position on a physical surface (Brenner & Smeets, 1997; Veerman et al., 2008; Oostwoud Wijdenes et al., 2013). Thus, the lack of clear short-latency responses in conditions without friction is not in conflict with our theory, it is a consequence of the relation between external damping and feedback gains set by the control policy.

It is tempting to interpret the fast responses in terms of vector coding of movement (Blouin, Cluff & Scott, 2016). In this coding scheme, the information that governs the response is the vector difference between the positions of the target and the end-effector. If vector coding would be used, one would expect that if both the target and the end-effector are displaced, there would be no response. We have tested this prediction by asking subjects to use a mouse on the table to move a cursor to a target on a vertical computer screen (Brenner & Smeets, 2003). When the target or cursor jumped, subjects responded at similar short latencies. When both jumped in the same direction, there was a small but clear response in the same direction as when only the cursor jumped. Apparently, the position of the target and end-effector are used independently in the control policy. More recently, we showed that not only the target and cursor are processed differently in feedback control, but it also matters whether the target is a virtual object or a gap between two virtual obstacles (Aivar et al., 2015).

We would like to end our response with some thoughts on the neural basis of the responses. Several commentators (Gielen, Cluff & Scott, 2016; Sainburg & Mutha, 2016) argue that this is essential for understanding fast responses. Neurophysiological data such as EMG measurements introduce many additional problems (note that the filtering issue mentioned by Cluff & Scott (2016) also holds for kinematics; Schreven et al., 2015), but we agree that understanding the neural mechanisms underlying behavior can be very interesting. However, we disagree with the idea that understanding neural mechanisms is essential for understanding behavior. The reason is that there is no a priori reason to believe that the stage of detection is performed within a dedicated neural structure or circuit. It is in principle possible that the same neurons that mediate a fast response also mediate normal reaction times. In this respect, our reasoning about the fast and slow responses is similar to the argument of Maurice Smith and colleagues that the "fast and slow adaptive processes … might even be part of the adaptive mechanisms of single synapses or single neurons" (Smith et al., 2006, p1041–1042). Although the question whether the same or different neural structures mediate the two types of responses might be interesting, the answer to that question has no effect on the interpretation at the behavioral level.

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