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Disambiguating the cognitive and adaptive effects of contextual cues of an impending balance perturbation

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ABSTRACT

Contextual cueing advancing the characteristics of an impending balance perturbation has been thought to induce optimized automatic postural responses. In this investigation, we aimed to disambiguate the cognitive and adaptive components of cueing a balance perturbation through the direction sequence of a series of base of support translations. We compared three experimental conditions: (a) block, with one perturbation cueing that the following one would be in the same direction; (b) serial, with one perturbation cueing that the following one would be in the opposite direction; and (c) random, representing a control uncued condition. Participants were instructed about the perturbation sequences. With this arrangement, at the cognitive level there was no directional uncertainty both in the block and serial sequences, while at the non-cognitive level only the block sequence was expected to lead to optimized responses in comparison to the random sequence. Results showed that the block sequence led to the generation of more stable automatic postural responses in comparison to the serial and random sequences, as indicated by lower amplitudes of body sway and lower velocity of center of pressure displacement. Increased balance stability in the block sequence was associated with longer delays of activation onset of leg distal muscles. Comparisons between the serial and random perturbation sequences failed to show any significant differences. These results indicate that optimized postural responses in the block sequence are due to adaptive processes underlying repetitive perturbations over trials rather than to processing of contextual cues at the cognitive level reducing uncertainty about characteristics of an impending perturbation.

1. Introduction

Generation of timely and scaled automatic postural responses (APRs) is mandatory to prevent critical body balance disequilibrium following an extrinsic perturbation to upright stance (cf. Azzi, Coelho, & Teixeira, 2017). Production of APRs has been proposed to be optimized by processing at higher order levels of control contextual cues informing in advance one or more characteristics of an impending body balance perturbation (Horak, Diener, & Nashner, 1989, Prochazka, 1989). Processing of predictive contextual cues is thought to lead to optimized APRs as a result of feedforward signals from higher to lower levels of postural control in the nervous system (Jacobs & Horak, 2007). Based on this proposition, one would expect that in conditions in which the physical characteristics of an impending balance perturbation can be anticipated the respective postural responses should be optimized in comparison with

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those responses produced under event uncertainty. Support for this proposition has been assumed from Smith's, Jacobs, and Horak (2012) results in the analysis of APRs to different amplitudes of translation of the support base. In that study, displacement amplitude was cued by means of repetitive (block) perturbations, maintaining the same amplitude of base of support translations across a sequence of trials. A random sequence of displacement amplitudes of the support base across trials was used as a control condition of uncued perturbations. Results revealed that in the block sequence center of pressure (CoP) under the feet showed a slower initial displacement following perturbations in comparison with the random sequence, suggesting more stable postural responses (see also Beckley, Bloem, Remler, Roos, & Van Dijk, 1991, Gilles, Wing, & Kirker, 1999, Smith, Jacobs, & Horak, 2014). The authors interpreted that result as supporting the notion that APRs are optimized in situations in which contextual cues advancing the perturbation characteristics are available. However, although a repetitive sequence of perturbations can be considered as a contextual cue reducing uncertainty about an impending balance perturbation, a confounding factor should be noted in that experimental approach. In addition to serving as a contextual cue of an impending perturbation, a sequence of equal perturbations across trials may have induced optimization of postural responses through adaptation processes (cf. Mierau, Hulsdunker, & Struder, 2015, Oude Nijhuis et al., 2009, Tang, Honegger, & Allum, 2012, Welch & Ting, 2014). Welch and Ting (2014), for instance, found reduced center of mass excursion/velocity and decreased muscular activation resulting from repetitive equal balance perturbations through a series of support base translations. The authors propose that adaptation of APRs over repeated perturbations is due to modification of central sensitivity to proprioceptive feedback in the search for response optimization. Modulation of proprioceptive feedback gains has been proposed as underlying improved balance stability following the first trial in a sequence of equal balance perturbations (Oude Nijhuis et al., 2009, Tang et al., 2012). From this perspective, it is possible that the assumed stabilizatory effect of cueing the characteristics of an impending perturbation by means of block trials on APRs, suggesting intervention of higher order processing, may have been due to adaptation taking place at a lower non-cognitive level of balance control.

The possibility that modulation of APRs in previous research (Beckley et al., 1991, Gilles et al., 1999, Smith et al., 2014, 2012) is due to adaptation over repetitive equal perturbations rather than to cognitive processing of contextual cues has been recently evaluated (Coelho & Teixeira, 2017, Experiment 1). In that study, we used an experimental setup similar to that employed by Smith et al. (2014, 2012), assessing APRs to three amplitudes of backward translation of the support base. In half the trials, participants were provided with explicit visual cues advancing the amplitude of the impending balance perturbation (in comparison with no visual cueing); another factor in the experimental design was sequence perturbation amplitudes, with half the perturbations being applied in a block and half a random sequence. Results showed that the block perturbations resulted in increased APRs stability, in addition to reduced onset delays between activation of the torso and distal leg muscles. Conversely, provision of cues on amplitude of the impending balance perturbation led to no effects on APRs generation. This finding suggests that the assumed modulation of APRs from higher order processing of contextual cues (e.g., Smith et al., 2014, 2012) seems to be in fact due to adaptation of postural responses over a series of equal balance perturbations. This conclusion is consistent with previous investigation failing to reveal the effect of explicit cueing on modulation of APRs to a sudden displacement of the support base while standing (Diener, Horak, Stelmach, Guschlbauer, & Dichgans, 1991, Fujio, Obata, Kawashima, & Nakazawa, 2016, Silva et al., 2015).

While the reviewed literature suggests that processing of contextual cues is unable to optimize postural responses to balance perturbations, a possibility remains that contextual cues can be more effective when provided by means of proprioceptive cueing. As modulation of postural responses by predictive cueing has been achieved through a sequence of equal perturbations (e.g., Smith et al., 2014, 2012), it could be thought that proprioceptive afference from the previous trial cueing the characteristics of the ensuing perturbation is used by the control system more effectively than explicit visual cues. From this perspective, further insight into the role of processing of contextual cues on APRS generation could be achieved from the comparison between different sequences of perturbations, so that one perturbation is used to cue the ensuing one without recurring to explicit verbal cueing. In the present investigation, we compared three experimental conditions manipulating directional cues of the impending balance perturbation: (a) block, with repetitive perturbations in the same direction; (b) serial, alternating perturbation directions between trials; and (c) a random sequence of perturbation directions. With this experimental arrangement, at the cognitive level both the block and serial sequences were performed under directional certainty, so that one is similarly aware of the response requirements of the impending perturbation in both the block and serial perturbation sequences. At the non-cognitive level, on the other hand, the repeated equal perturbations of the block sequence favored intertrial adaptation (cf. Welch & Ting, 2014), whereas the serial and random sequences were maladaptive by requiring different postural responses between consecutive trials (cf. Oude Nijhuis et al., 2009). From these comparisons, then, we contrasted the cognitive (uncertainty) and noncognitive (adaptation) components of perturbation cueing provided by the sequence of perturbations. If sequence of perturbations is used as cueing leading to optimized reactions, one would hypothesize that both block and serial cueing conditions lead to improved postural responses. Otherwise, if the effect of sequence of equal perturbations is due to adaptation by repeated exposure to the same balance perturbation, the alternative hypothesis is that only block perturbations lead to improved postural responses in comparison to the random sequence.

2. Methods

2.1. Participants

Twelve healthy university students (8 males), age range 18–31 years ($M = 23.42$, $SD = 3.94$), participated in this study. Inclusion criteria were absence of neurological or musculoskeletal diseases at the time of experiment that might affect postural control, as self-declared. All participants provided informed consent, and experimental procedures were approved by the local university ethics committee, in accordance with the ethical standards established in the Declaration of Helsinki.