On the Dynamical Nature of Human Postural Transitions

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Analyses of postural states (and changes between them) have been a major focus of research in the neuro-muscular approach to postural coordination pioneered by Nashner (e.g., Nashner & McCollum, 1985). In a somewhat different context, we have recently focused our attention on the emergence of these postural states as well as on the constraints that shape their dynamics (Bardy, Marin, Stoffregen, & Bootsma, in press; Marin, Bardy, Stoffregen, Baumberger, & Flückiger, in press; Marin, Bardy, & Bootsma, in press). In this series of studies, standing participants who were asked to follow with their head the displacement of a target oscillating along the line of sight exhibited two preferred coordination modes for movements of the ankles and hips: An in-phase mode, with the two joints moving simultaneously in the same direction (ϕ_r close to 0°), and an anti-phase mode with the two joints oscillating simultaneously in opposite directions (ϕ_r close to 180°). The emergence of either one of these two phase relations depended on the interaction between environmental, intrinsic, and intentional constraints. In the present experiment, we focus on the (non-linear) properties of transitions between these postural states.

Method

Participants (*N* = 12) stood upright with arms crossed at 1.60 m from a large screen (3.00 m H x 2.25 m V). A computer-generated target (INDY 486 XZ Silicon Graphics workstation) — a 0.56 m x 0.51 m white square against a black background — was rear-projected on the screen via an Electrohome 7500 video-projector. The target oscillated along the antero-posterior (AP) direction with a peak-to-peak amplitude of ~1 cm. Participants were instructed to track the target motion with their head and to keep the distance between their head and the target constant. Target frequency served as the control parameter, i.e., as an unspecific parameter used to move the postural system through different collective states. In the *Up* condition, target frequency was increased from 0.05 Hz to 0.80 Hz in steps of 0.05 Hz. In the *Down* condition, it decreased from 0.80 Hz to 0.05 Hz in similar steps. Each frequency step lasted for 10 oscillation cycles, leading to a total of 12 minutes per condition. Two trials were performed in each condition. Trial order was counterbalanced across participants.

The AP motion of the head was recorded via a string attached to a potentiometer, and the angular motion of the right ankle and right hip were recorded with two electro-goniometers. These devices were sampled at 20 Hz, and three dependent variables were derived: (i) the (point estimate value of) relative phase ϕ_r between ankle and hip motion, which served as the order parameter for characterising the coordination pattern, the (ii) transition time (*TT*) between in-phase and anti-phase modes, and (iii) transition frequency (*TF*). This last variable was used to test for hysteresis effects, i.e., for the existence of differences in *TF* between *Up* and *Down* conditions. Measures for central tendency and variability of ϕ_r were obtained using circular statistics (Batschelet, 1981).

Results and discussion

One participant was excluded from the analysis because he did not fulfil the task requirements (head-target gain < 0.25). Figure 1A illustrates the evolution of ϕ_r as a function of target frequency for six individual trials (three in each condition), and Figure 1B presents the averaged ϕ_r values for the eleven participants in each of the two conditions. Because the transition frequency differed across participants, 18 segments were defined for each individual trial, centred around the first cycle following the transition. Each segment included the mean relative phase of four cycles, with an overlap of two cycles (see Kelso, Scholz, & Schöner, 1986, for a similar analysis).

Insert Figure 1 here

Examination of Figure 1 indicates the emergence of only two postural modes, an in-phase mode (ϕ_r close to 20°) at low target frequencies, and an anti-phase mode (ϕ_r close to 180°) at high target frequencies, confirming previous work (e.g., Bardy et al., in press). All participants switched from one of these two modes to the other as target frequency increased or decreased, with an average *TT* of 1.41 cycles (*SD* = 0.87) in the *Up* condition and 1.63 cycles (*SD* = 0.83) in the *Down* condition. All together, 68% of the transitions occurred in less than one cycle, and 86% in less than two cycles. Finally, an hysteresis effect was found (*TF* was higher in *Up* as compared to Down, see Figure1A), $t(21) = 3.04$, $p < .01$.

Conclusion

The results strongly suggest that changes between postural coordination modes during supra-postural tasks behave like non-linear phase transitions (Haken, 1983), exhibiting loss of stability (as evidenced by an increase of fluctuations during approach to the transition region), bifurcation, and hysteresis. The analysis of relative phase dynamics in postural control thus provides new insights into changes between postural states (cf. Nashner & McCollum, 1985). Perturbation experiments using optically specified shifts in relative phase are now in progress to evaluate stability properties of these two postural modes.

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Figure caption

Figure 1. (A) Ankle-hip relative phase ϕ_r as a function of target frequency for three individual trials in *Up* and *Down* conditions; (B) Means and standard deviations of ϕ_r for the eleven participants in both conditions. Each segment includes a temporal average of ϕ_r over 4 cycles of oscillation.