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Short-term differential training decreases postural sway

Eric G. James [*]

Department of Health and Human Performance, University of Texas at Brownsville, USA

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ABSTRACT

Differential training has been shown to enhance motor learning in sports skills. In the present study differential training was applied to the minimization of postural sway. A differential training group performed 15 one minute practice trials, each with different postural movement instructions. A repetitive practice group performed 15 trials standing as still as possible for one minute. Pre- and post-tests were performed standing as still as possible in 1 and 2-leg stance. Accelerometry data were collected approximately at the level of the center of mass (COM) and at the head. The root mean square jerk (RMSJ) of movement at the COM and head was estimated for the anteroposterior and mediolateral axes of motion. A significant Group × Test interaction revealed that the differential training led to lower anteroposterior RMSJ on the post-test than on the Pre-test in both the 1 and 2-leg stance tasks. A significant Group × Effector × Test interaction revealed that the decrease in anteroposterior RMSJ with differential training occurred in the RMSJ of the head but not the COM. The repetitive practice did not lead to a significant change in anteroposterior RMSJ at either the COM or the head. Neither form of training led to a significant change in mediolateral RMSJ. The results indicated that differential training can enhance motor learning not only in complex sports skills but in relatively simple motor tasks such as maintaining quiet stance.

1. Introduction

In the dynamic systems perspective of motor behavior fluctuations in motor output are not merely error that need to be eliminated. In modeling from the dynamic systems perspective the presence of Gaussian noise has been hypothesized to interact with the stability properties of the intrinsic dynamics to influence the occurrence of phase transitions [27]. The magnitude of perturbations and the stability of attractive states also influence the relaxation time for a system to return to a stable state [19]. One example of the introduction of stochastic perturbations to the neuromotor system is the application of vibratory stimulation ('stochastic resonance'). Stochastic resonance, a form of vibratory noise applied to the soles of the feet (or other part of the body), has been shown to enhance postural control [20] and the functioning of sensory systems [5].

Stochastic perturbations have been hypothesized to play a critical role in motor learning. Schöllhorn and colleagues [9,25,26] hypothesized that the rate of motor learning follows dynamic principles with the magnitude of perturbations a control parameter and the learning rate an order parameter. In this theoretical view perturbations beyond a threshold magnitude produce a bifurcation from bistability to monostability in the motor learning dynamics. This hypothesis is consistent with simulated annealing (such as in artificial neural networks), in which a threshold magnitude of stochastic perturbations is necessary to escape from a false local minimum so as to encounter the global minimum [14,26].

In motor learning false local minima correspond to suboptimal task solutions and the global minimum to the optimal task solution. The introduction of stochastic perturbations to movement patterns via movement instructions during practice has been associated with an exploratory process of motor learning [21,25,26]. Research has also shown that the introduction of noise into training, in the form of multiple movement pattern variations, leads to greater performance and learning in a number of motor tasks [9,25,26]. These findings suggest that traditional approaches to motor learning and rehabilitation may benefit from the introduction of higher levels of noise.

In differential learning the noise level during training is increased by providing instructions for the practice of multiple movement variations, with a short amount of time spent performing each variation. The instructions can vary movement characteristics such as the initial and/or ending conditions of a movement, the relative and/or absolute duration of movement, joint angles, velocities and acceleration profiles etc. [25]. In

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[*] Corresponding author at: Department of Health and Human Performance, The University of Texas at Brownsville, REK Building 2.638, Brownsville, TX 78520, USA. Tel.: +956 882 5944; fax: +956 882 7348.

E-mail address: Eric.James@utb.edu

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modeling of differential learning [9], the motor learning dynamics landscape is initially bistable, with one stable attractive state corresponding to a learning rate of zero and the other with a positive learning rate. Prior to practice the system typically resides in the stable state with a motor learning rate of zero. Perturbations introduced by the movement instructions cause the intrinsic learning dynamics to bifurcate from bistability to monostability, with a single stable state with a positive rate of motor learning. After differential training has ended the system again becomes bistable and a hysteresis effect occurs, with the system remaining in the stable attractor state with a positive learning rate for a period of time [9]. As traditional forms of practice [1,24] are designed to reduce the variability of movement characteristics the perturbations present in these forms of practice likely do not exceed the threshold level necessary to produce a bifurcation in the learning dynamics.

To date, research has examined how differential training affects motor learning in complex sports skills [2,25] but has not examined the effects of differential training on relatively simple motor tasks. The present study examined the effects of differential training on quiet 1 and 2 leg stance. It was hypothesized that differential postural training would lead to a greater decrease in postural sway than repetitive training.

2. Methods

2.1. Participants

Healthy young adult participants ($N = 33$; 14 males, 19 females) with a mean age of 25.18 ($SD = 4.19$) years volunteered for this study. All participants signed an informed consent form that was approved by the local Institutional Review Board. All participants identified themselves as having had no prior surgery or injury to the lower extremities. The participants were randomly assigned to either a differential (DL; $n = 16$) or repetitive (REP; $n = 17$) practice group.

2.2. Tasks and procedures

Two biometrics (Ladysmith, VA) ACL300 3-D accelerometers were attached to the posterior of the head and of the trunk approximately at the level of the center of mass (COM). DataLINK software was used to collect acceleration data at a sampling rate of 1000 Hz during movement trials. The accelerometer on the posterior side of the trunk was attached with adhesive tape approximately behind the COM (approximately at the level of the 2nd sacral vertebra). The other accelerometer was attached to the back of a hat that was worn by participants during testing. Each participant performed 1 trial of 30 s duration for each of 2 postural tasks. Task 1 consisted of 2 leg stance with the eyes open. Task 2 was balance on only the preferred leg with the eyes open. The participants were instructed to look at a dot located on a wall 1.5 m in front of them and to stand as still as possible in each task. The order of task presentation was counterbalanced across participants and the two tasks were each performed on a Pre-test and Post-test before and after 15 postural training trials. Fifteen minutes of seated rest was given between the postural practice and the Post-test.

The movement training trials were performed standing on both feet with the eyes open. The DL and REP training groups each performed 15 postural training trials of 1 min duration with 30 s rest between trials. The movements performed by the DL group are shown in Table 1. The order of the movement trials was randomized for each participant. For the REP group the 15 postural training trials consisted of standing as still as possible in a normal stance.

2.3. Data analysis

The anteroposterior (AP) and mediolateral (ML) acceleration data were filtered with a 9th order 20 Hz low pass Butterworth filter. A Butterworth filter was used as this type of filter approximates the passband of an ideal filter. A cutoff frequency of 20 Hz was used as the power spectrum of postural sway is well known to be well below this frequency. The jerk (i.e., the first derivative) of the acceleration data was calculated via a finite difference equation. The root mean square jerk (RMSJ) was then calculated for the AP and ML axes of motion for each accelerometer. The RMSJ was used to estimate postural sway as the neuromotor system has been found to minimize jerk [8] and this variable has previously been used to estimate postural sway [15].

Two 2 (Group) × 2 (Effector) × 2 (Stance) × 2 (Test) ANOVA were used to analyze the RMSJ data from the AP and ML axes of motion. The calculation of all dependent variables was performed with coded MATLAB (Mathworks, Natick, MA) programs. Inferential statistical analyses were performed using the SPSS software package (version 21.0) and an alpha of 0.05 was used to determine statistical significance.

3. Results

3.1. Anteroposterior root mean square jerk

In the ANOVA of the AP RMSJ there was a significant effect for stance, with the 2 leg stance RMSJ significantly lower than the 1 leg stance, $F(1,31) = 102.032$, $p < 0.001$. There was a significant effect

Table 1
The information contained in the instructions for postural training trials for the differential learning group. The instructions pertained to the stance, the distribution of weight over the feet, and movements of the body. The order of instructions was randomized for each participant and each instruction was performed for 1 trial of 1 min duration.

	Stance	Weight position	Movement
1	Normal	Normal	Rotate upper torso/shoulders left and right without moving the head or pelvis
2	Normal	Normal	Rotate the pelvis left and right without moving the head or shoulders
3	Normal	Normal	Rotate the pelvis and shoulders in opposite directions
4	Normal	Normal	Rotate the head and pelvis in opposite directions
5	Normal	Normal	Rotate the head and shoulders in opposite directions
6	Narrow	Over heels	Lean with entire body left and right
7	Narrow	Over balls of feet	Lean with entire body left and right
8	Wide	Over heels	Lean with entire body left and right
9	Wide	Over balls of feet	Lean with entire body left and right
10	Narrow	Over left foot	Lean with entire body forward and backward
11	Narrow	Over right foot	Lean with entire body forward and backward
12	Wide	Over left foot	Lean with entire body forward and backward
13	Wide	Over right foot	Lean with entire body forward and backward
14	Normal	Normal	Lean with entire body in clockwise circles
15	Normal	Normal	Lean with entire body in counterclockwise circles