Journal of Biomechanics xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

Characterizing the balance-dexterity task as a concurrent bipedal task to investigate trunk control during dynamic balance

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ARTICLE INFO

Article history:
Accepted 4 July 2018
Available online xxxx

Keywords:
Balance
Perturbation
Trunk control
Bipedal

ABSTRACT

The purpose of the study was to characterize the Balance-Dexterity Task as a means to investigate a concurrent bipedal lower-extremity task and trunk control during dynamic balance. The task combines aspects of single-limb balance and the lower-extremity dexterity test by asking participants to stand on one limb while compressing an unstable spring with the contralateral limb to an individualized target force. Nineteen non-disabled participants completed the study, and performance measures for the demands of each limb – balance and dexterous force control – as well as kinematic and electromyographic measures of trunk control were collected. Given five practice trials, participants achieved compression forces ranging from 100 to 139 N (mean 121.2 ± 12.3 N), representing 14.4–23.0% of body weight (mean 18.7 ± 2.4%), which were then presented as target forces during test trials. Dexterous force control coefficient of variation and average magnitude of the center of pressure (COP) resultant velocity were associated such that greater variability in force control was accompanied by greater COP velocity ($R = 0.598$, $p = 0.007$). Trunk coupling, quantified as the coefficient of determination (R^2) of a frontal plane thorax and pelvis angle-angle plot, varied independently of any measure of balance or dexterous force control. The Balance-Dexterity Task is a continuous, dynamic balance task where bipedal coordination and trunk coupling can be concurrently observed and studied.

1. Introduction

The purpose of this study was to characterize the Balance-Dexterity Task and to evaluate its use in investigating a concurrent bipedal lower-extremity task and trunk control during dynamic balance (Fig. 1). The Balance-Dexterity Task was developed by combining single-limb balance (Schneiders et al., 2010) with the lower-extremity dexterity test (LED-test) (Lyle et al., 2013a). The traditional LED-test involves compression of an unstable spring while semi-seated on a bicycle seat with arms resting on a support surface and quantifies lower-limb dexterity since the compression force achieved is associated with performance on the cross-agility test ($R^2 = 0.63$) but not hip extensor strength ($R^2 = 0.04$), knee extensor strength ($R^2 < 0.01$), or knee flexor strength ($R^2 = 0.02$) (Lyle et al., 2013a, 2013b). In investigating athletic performance measures with a principal component analysis approach, dexterous force control and balance were found to quantify distinctly different aspects of performance (Lawrence et al., 2015). Adding this dexterous force control demand to the balance demands of single-limb stance can be viewed as a concurrent lower-extremity bipedal task and allows us to study motor control processes involved in successful task execution.

The characterization framework started by quantifying and evaluating performance measures for the demands of each limb – balance and dexterous force control – then continued by examining relationships between these measures. Next, trunk coordination was quantified and associations between trunk coordination and task performance measures were tested. Finally, factors potentially contributing to trunk coordination were explored including muscle activation data.

2. Methods

2.1. Participants and instrumentation

Nineteen non-disabled participants with no back or lower-extremity injury or pain in the last year and no conditions which would affect balance were recruited for the study with Institutional Review Board approval and informed consent (12 females, 7 males; 23.9 ± 3.3yrs; 169.1 ± 10.4 cm; 67.1 ± 10.8 kg; BMI 23.3

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https://doi.org/10.1016/j.jbiomech.2018.07.014
0021-9290/

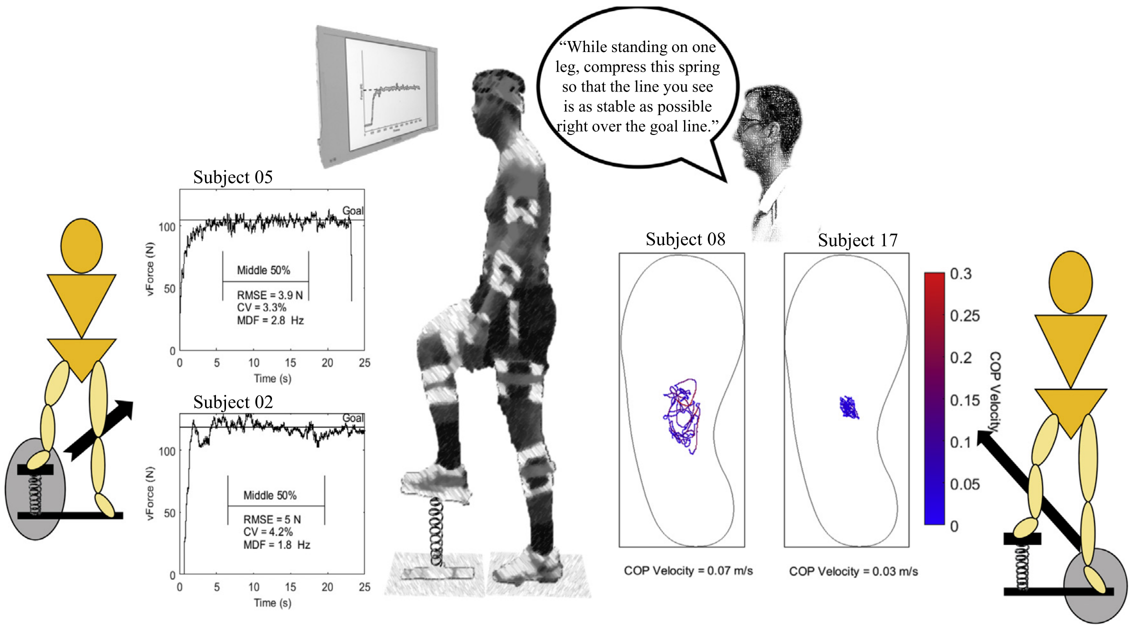

Fig. 1. The Balance-Dexterity Task with representative data showing examples of highest and lowest balance outcome measures including center of pressure (COP) measures (right) and dexterous vertical force (vForce) control outcome measures including root-mean-squared error (RMSE), coefficient of variation (CV) and median frequency (MDF) (left).

± 1.8). Participants were instrumented with a full-body retroreflective marker set as well as surface electromyography (EMG) of the external oblique (EO), rectus abdominis (RA), and gluteus maximus (GMax) and medius (GMed) and fine-wire EMG of the internal oblique (IO), lumbar multifidus (MF), and erector spinae (ES) at the level of L4 (Noraxon Wireless EMG; Scottsdale, AZ; 3000 Hz). Surface EMG were collected with bipolar silver/silver chloride electrodes with an interelectrode distance of 22 mm placed per guidelines from SENIAM (Hermens et al., 2006), and fine-wire EMG were collected with a pair of 50 µm nickel-chromium alloy wires insulated with nylon with distal 2 mm exposed and loaded into a 25-gauge hypodermic needle and sterilized. Insertions were done under ultrasound guidance, and protocols were adapted from Perotto et al. (2011). All muscles were instrumented on the side contralateral to the participant's preferred kicking limb, hereafter referred to as the stance side. Motion data were captured with an 11-camera Qualisys Oqus System (Gothenburg, Sweden; 250 Hz), and kinetic data were captured with Advanced Medical Technology Inc. force plates (Watertown, MA; 3000 Hz).

2.2. Procedures

Participants completed a 30 s trial of double-limb standing (preferred stance width) and three 30 s trials of single-limb standing on the stance side. Participants were introduced to the Balance-Dexterity Task, which used a custom device made by mounting polyvinyl chloride (PVC) adaptors to boards with a spring between them (spring characteristics: outside diameter 1.750 in [4.445 cm], inside diameter 1.336in [3.393 cm], free length 12.0in [30.48 cm], rate 28.0 lbs/in [49.0 N/cm], wire diameter 0.207 in [0.526 cm], and total coils 27.5; Compression Spring #805, Century Spring Corp., Commerce, CA). A similar instrumented device is available from Neuromuscular Dynamics, LLC (La Crescenta, CA). Participants were shown real-time feedback of the vertical force under the spring, and instructed: "While standing on one leg, compress this spring so that the line is first as high, then as stable as possible" (Fig. 1). Each trial lasted 20–25 s. After one familiarization trial and five practice trials, the mean of the middle 50% of the last three practice trials were used to calculate an individual's individualized target compression force. This value is different from the compression force achieved during the traditional LED-test because (1) the goal of the Balance-Dexterity Task, in contrast to the LED-test's goal of measuring maximum dexterous control ability, is to use dexterous force control to perturb balance; (2) for the LED-test, at least 20–25 attempts are required to produce a stable maximum indicating the compression described here is not maximal (Lyle et al., 2013a, 2013b); (3) in pilot testing it was found that, without the seat and arm rests, giving subjects more than five practice trials to achieve a stable maximum led to creative but confounding strategies sometimes including a deep squat with the stance leg or wedging the spring into a contorted shape. Note that the compression forces achieved cannot be directly compared to the Lyle et al. series of studies because spring stiffness parameters were different – 36.8 N/cm (Lyle et al., 2013a) and 49.0 N/cm in the current study. In addition, a direct comparison is not warranted because of the methodological differences between the LED-test where lower-extremity dexterity capability is quantified and the Balance-Dexterity Task where dexterous force control (not necessarily one's maximum capacity) is used to perturb standing balance. After practice, participants used a visual analog scale (VAS) to report how difficult the task was (0 Anchor: "Not difficult at all" and 10 Anchor: "Extremely difficult"), how confident they were they could complete the task successfully (0 Anchor: "Not confident at all" and 10 Anchor: "Extremely confident"), and how much attention the task required (0 Anchor: "No attention at all" and 10 Anchor: "All my attention").

Participants then completed five trials where a dotted line on the computer screen indicating their individualized target was shown with the instructions: "While standing on one leg, compress this spring so that the line is as stable as possible directly over the dotted goal line." Three trials were interspersed where the spring was replaced with a stable block of the same height, and the same target instructions were given. Five participants were brought in on a separate day for re-testing to assess test-retest reliability of outcomes measures. Results are reported as two-way random effects model ICC(2,5)s for absolute agreement, standard error of