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Stability of Measurement Outcomes for Voluntary Task Performance in Participants With Chronic Ankle Instability and Healthy Participants

Sara Van Deun, PhD, PT*; Karel Stappaerts, PhD*; Oron Levin, PhD†; Luc Janssens, Ing‡; Filip Staes, PhD, PT*

*Research Centre for Musculoskeletal Rehabilitation and †Research Centre for Movement Control and Neuroplasticity, Katholieke Universiteit Leuven, Belgium; ‡Group T Engineering School, Leuven, Belgium

Context: Acceptable measurement stability during data collection is critically important to research. To interpret differences in measurement outcomes among participants or changes within participants after an intervention program, we need to know whether the measurement is stable and consistent.

Objective: To determine the within-session stability of muscle activation patterns for a voluntary postural-control task in a group of noninjured participants and a group of participants with chronic ankle instability (CAI).

Design: Descriptive laboratory study.

Setting: Musculoskeletal laboratory.

Patients or Other Participants: Twenty control participants (8 men, 12 women; age = 21.8 ± 2.4 years, height = 164.3 ± 13.4 cm, mass = 68.4 ± 17.9 kg) and 20 participants with CAI (12 men, 8 women; age = 21.2 ± 2.1 years, height = 176 ± 10.2 cm, mass = 71.7 ± 11.3 kg).

Intervention(s): Participants performed 4 barefoot standing trials, each of which included a 30-second double-legged stance followed by a 30-second single-legged stance in 3 conditions: with vision, without vision, and with vision on a balance pad.

Main Outcome Measure(s): The activity of 7 muscles of the lower limb was measured for the stance task in the 3 different conditions for each trial. The onset of muscle activity and muscle recruitment order were determined and compared between the first and the fourth trials for both groups and for each condition.

Results: We found no differences in the onset of muscle activity among trials for both groups or for each condition. The measurement error was 0.9 seconds at maximum for the control group and 0.12 seconds for the CAI group. In the control group, 70% to 80% of the participants used the same muscle recruitment order in both trials. In the CAI group, 75% to 90% used the same recruitment order.

Conclusions: Within 1 session, measurement stability for this task was acceptable for use in further research. Furthermore, no differences were found in measurement stability across conditions in the control or CAI groups.

Key Words: muscle activity, latency, muscle recruitment order, consistency

Key Points

- Measurement stability was not different across conditions in the control or chronic ankle instability groups.
- Muscle activation onset was not different between the first and fourth trials within each group or condition.
- The percentage of agreement for muscle recruitment order ranged from 70% to 80% in the control group and from 75% to 90% in the chronic ankle instability group.
- Measurement stability for this task is acceptable for use in further research.
- Future researchers should consider the muscle activation patterns during voluntary perturbations.

Ankle sprains are among the most common injuries seen in daily life and sport activities.[1] Approximately 40% of the patients who have a lateral ankle sprain develop chronic ankle instability (CAI).[2–4] Chronic ankle instability is characterized by recurrent ankle sprains and a feeling of the ankle "giving way" with slight or no external perturbation.[5,6] Altered muscle activation is thought to be an important factor that might contribute to reinjury after a lateral ankle sprain.[7] Most researchers who have examined this phenomenon in participants with CAI have focused on the latency of the peroneus longus muscle during a sudden ankle inversion.[8–11] The neuromuscular function of this muscle is critical to the dynamic support of the ankle-foot complex and to the prevention of injuries.[9]

Acceptable measurement stability during data collection is critically important to research.[12,13] To interpret differences in measurement outcomes among participants or changes within participants after an intervention program, we need to know whether the measurement is stable and consistent. Before a test procedure, such as peroneus longus latency, is accepted as a

clinical measurement method, acceptable measurement stability (ie, the degree of consistency and agreement of the test results among repeated measures) must be demonstrated.[12,13]

In the literature, little attention has been paid to the stability of measurements of electromyography (EMG) for the ankle region. Eechaute et al[14] investigated the test-retest reliability with a 1-week interval of outcome measurements of a sudden ankle inversion movement in participants with healthy ankle joints. One of the variables investigated in their study was the latency of the peroneus longus muscle.[14] The authors reported intraclass correlation coefficients (ICCs) and standard errors of measurement (SEMs). Values of ICC (3,1) ranged from 0.71 to 0.83 and of SEM ranged from 8.4 to 6.3 milliseconds. As a general guideline, reliability coefficients less than 0.50 represent poor reliability, from 0.50 to 0.75 reflect moderate to good reliability, and more than 0.75 indicate good to excellent reliability.[15] Based on the ICC and SEM, Eechaute et al[14] concluded that the reliability of the peroneus longus latency time was acceptable in participants with healthy ankle joints, supporting the use of this outcome measure in further research. Benesch et al[16] examined the reliability of peroneal reaction time measurements during a sudden inversion movement of the ankle in healthy participants and found that the reliability coefficient (Spearman ϱ) was 0.67. From this study, peroneal reaction time appeared to be a reliable measurement method to be used in future investigations as a clinical test variable. Investigating the latency of the peroneus longus muscle during a sudden ankle inversion movement in normal ankles, Hopper et al[17] reported high ICCs for the right (ICC = 0.91, SEM = 10.07 milliseconds) and left (ICC = 0.89, SEM = 9.96 milliseconds) legs. The authors of each described study focused on healthy, noninjured participants.[14,16,17] Stability of these measures in participants with CAI is unknown.

Compared with the number of researchers investigating muscle responses to sudden perturbations, even fewer have investigated voluntary postural-control tasks. The ability to maintain postural control requires that the neuromuscular control system adapt to various task variables of either internal or external origin.[18] An inefficient neuromuscular control system might not adapt well to different perturbations, resulting in impaired performance and injury.[18] Inputs from visual, somatosensory, and vestibular systems are important sources for performing postural control tasks.[19] When environmental conditions change, the central nervous system must adapt to the different situation and selectively focus on the sensory inputs that are providing the most reliable information.[18] Withdrawing vision requires the hierarchy of sensory signals to be reorganized because somatosensory and vestibular signals become the only sources, whereas the introduction of unstable support surfaces alters the somatosensory signals at the ankle and increases the reliance on proximal somatosensory, visual, and vestibular signals.[20]

Van Deun et al[21] investigated muscle activation patterns shown by control participants and participants with CAI during the transition from a double-legged to a single-legged stance position. The onset of muscle activity and muscle recruitment order of 11 muscles of the lower limb and trunk were measured under 2 conditions (with vision and without vision) using surface EMG. The ability to switch from double-legged to single-legged stance is needed for many everyday activities, such as walking, running, and climbing stairs. Furthermore, the transition task is a frequently used clinical tool for assessing and rehabilitating patients with CAI. The results of their study demonstrated a later onset time for ankle and hip muscle activation during the transition from double-legged to single-legged stance in participants with CAI than in healthy control participants.[21] They also showed that participants with CAI tended to use the same muscle recruitment order in conditions with and without vision, whereas healthy control participants altered their recruitment order according to the changing situation.[21]

The findings in the study by Van Deun et al[21] were based on the results of 1 trial. A difference in muscle activation timing and order might be a contributing factor for CAI or a result of CAI that must be addressed in rehabilitation. To determine whether these measures are clinically important and acceptable for use in further research, measurement stability must be determined for this task in noninjured participants and participants with CAI and for different conditions. Therefore, our purpose was to assess the within-session stability of muscle activation patterns for a double-legged to single-legged stance task in a group of noninjured participants and in a group of participants with CAI under 3 conditions: with vision, without vision, and standing on a balance pad with vision. We were interested in 2 variables. The first variable was the onset time of muscle activity on the group level of 7 lower limb muscles. The second variable was the muscle recruitment order on the individual level.

METHODS

Participants

All participants included in the study were selected from the same population of university students of the Faculty of Kinesiology and Rehabilitation Sciences. A self-report questionnaire was used to determine whether participants met the criteria for the control group or the CAI group. The control group (8 men, 12 women; age = 21.8 ± 2.4 years, height = 164.3 ± 13.4 cm, mass = 68.4 ± 17.9 kg) included participants with no history of ankle, knee, hip, or lower back injury. The inclusion criteria for the CAI group (12 men, 8 women; age = 21.2 ± 2.1 years, height = 176 ± 10.2 cm, mass = 71.7 ± 11.3 kg) were a history of at least 2 sprains in the same ankle in the 2 years before the study, repeated episodes of giving way during daily activities, and no serious ankle trauma for the 3 months before the study. They were excluded if they reported bilateral ankle sprains, reported previous fractures or surgery in the lower limb or back, or were currently participating in a rehabilitation program. This definition of *CAI* was based on the criteria used in previous studies.[22–34] The number of ankle sprains reported in these studies ranged from 1[22–25] to at least 2[26–32] and to more than 3[33,34] ankle sprains. However, all studies included the presence of giving way in their definition of *CAI*.[22–34] To determine whether participants had repeated episodes of giving way, we asked whether they experienced a feeling of instability, insecurity, or the ankle giving way and, if so, during which activities and how often this occurred.

All participants included in the study were engaged in recreational or competitive sport activities and were physically active during their activities of daily living. To determine their physical activity levels, we used the Baecke Questionnaire of Habitual Physical Activity.[35] The Baecke questionnaire is an instrument that evaluates habitual physical activity over the previous 12 months. It is easily applied and understood, making use of qualitative and quantitative scales to assess the magnitude of occupational physical activity, physical exercise in leisure, and leisure and locomotion activities. Most of the questionnaire is scored on a 5-point Likert scale, with descriptors ranging from

never to *sometimes* to *very often*. Three additional questions require reporting the type of sport activity and both the number of hours per week and the number of months per year in which the respondent participated in that activity.[35]

Participants in the control group were matched with the participants in the CAI group with respect to age (within 12 months), body mass index (within 5%), and activity level (within 2 points on the total activity index determined by the Baecke questionnaire). All participants gave written informed consent, and the study was approved by the Medical Review Board of the University Hospitals Leuven and the Katholieke Universiteit Leuven.

Procedures

During data collection, participants were instructed to perform 4 standing trials, each consisting of 3 conditions that were presented to the participants in the following sequence: (1) a 30-second double-legged stance followed by a 30-second single-legged stance with vision; (2) a 30-second double-legged stance followed by a 30-second single-legged stance without vision; and (3) a 30-second double-legged stance followed by a 30-second single-legged stance on a balance pad with vision.

Under each experimental condition, participants stood barefooted on a force plate (model FP4060-07-1000; Bertec Corporation, Columbus, OH) with their feet separated by the width of their hips and with their arms hanging loosely at their sides. Participants were instructed to remain as motionless as possible during the double-legged stance phase; to transition to single-legged stance, which was set by an audible signal, as quickly as possible; and to remain as motionless as possible during the single-legged stance phase. For the single-legged stance phase, participants with CAI shifted their weight to the injured leg. In the control group, participants shifted their weight to the dominant or nondominant leg, and this was matched to the injured leg (dominant or nondominant) of the CAI participants. The *dominant leg* was operationally defined as the leg with which the participant would kick a ball.[21]

In the vision condition, participants were instructed to stare at a wall in front of them and to keep their gaze straight ahead. In the no-vision condition, participants wore special glasses that eliminated their vision (Figure 1). These glasses allowed participants to keep their eyes open during the experimental condition without being able to glance downward or sideward. For the balance-pad condition, a medium-density, viscous foam (height = 8 cm, width = 41 cm, length = 50 cm; Airex Balance Pad; Physiomed Services Ltd, Derbyshire, United Kingdom) was placed on top of the force plate. The balance pad allowed movement in all directions, creating a 3-dimensional wobble effect. The condition was repeated when excessive arm swing occurred or when the foot touched the force plate during the single-legged stance phase. After each trial, the participants were allowed to sit down for 1 minute to avoid fatigue.

Participants had to perform the transition task 4 times for each condition. In the literature, the number of trials necessary for determining latency values of muscle activation for analysis has varied from 1 trial[36] to a mean of 20 trials.[37] The number of trials in our study was based on pilot testing, in which participants reported feelings of fatigue or discomfort after 4 to 8 trials. Therefore, we chose 4 trials to avoid fatigue and pain, particularly in the CAI group. Measurement stability was determined between the first and fourth trial. If changes because of learning occurred between trials 1 and 2, 2 and 3, or 3 and 4, these changes would have been noticeable between the selected trials.

Data Collection

Foot-ground reaction forces and muscle activity from 7 muscles of the lower limb were measured during the transition from double-legged to single-legged stance. The temporal variations in the vertical, anteroposterior, and mediolateral directions of the foot-ground reaction forces were measured by the force plate and were collected at 500 samples per second.

Surface EMG signals were recorded using a 16-channel electrode system (MyoSystem 1400; Noraxon, USA Inc, Scottsdale, AZ) and were digitized at 2000 samples per second. The recording was made in differential mode using an amplifier with an input impedance of more than 100 MΩ and a common mode rejection ratio of 100 dB at 50 Hz. The noise level was lower than 1 μV root mean square. The actual gain was set at 1000, and an analog high-pass, second-order Butterworth filter at 10 Hz was used to minimize the influence of movement artifact. On the other side, a maximal flat, low-pass, eighth-order Butterworth filter at 1000 Hz minimized aliasing effects.[21,38] The EMG signals of the following muscles were recorded for the injured leg in participants with CAI and for the dominant or nondominant leg in control participants: gluteus maximus, gluteus medius, tensor fasciae latae, vastus lateralis of the quadriceps femoris, vastus medialis obliquus of the quadriceps femoris, tibialis anterior, and peroneus longus. Pregelled silver chloride surface electrodes with a 20-mm diameter (Ambu Blue Sensor P; Ambu A/S, Ballerup, Denmark) were placed over the muscle belly close to the motor point of the muscle and parallel to its longitudinal axis and with a center-to-center distance of approximately 20 mm. A reference electrode was placed over the anteromedial surface of the shank. Placement of the electrodes was based on the instructions of Basmajian and De Luca[39] and was checked with isolated manual muscle tests. The minimum distance between electrode pairs was set at 30 mm to reduce the possibility of crosstalk between neighboring muscles.[39] To increase electric conductance, the skin was shaved, abraded using a pumice, and degreased with 70% isopropyl alcohol before the electrodes were attached.

Force plate and EMG signals were registered by using a Micro 1401 data acquisition system (Cambridge Electronic Design Limited, Cambridge, United Kingdom) with 12-bit resolution and were recorded in real time by using the Spike 2 for Windows software package (version 5.01; Cambridge Electronic Design Limited). Before we exported the data for further analysis, participant information was removed and replaced by numbers. This made it impossible for the person who was responsible for the analysis to link the data to participant characteristics.

Data Analysis

Force plate and EMG signals from the 4 trials in each condition were exported from Spike 2 for Windows into a spreadsheet and loaded into LabVIEW (version 8.5; National Instruments Corporation, Austin, TX) for an offline analysis.

For the force plate data, the onset of displacement of the center of pressure in the mediolateral plane (COP_{ML}) was determined. The COP_{ML} was estimated using the following equation: $COP_{ML} = M_{AP}/F_Z$, where M_{AP} is the moment around anteroposterior components and F_Z is the vertical force. The onset of dis-

Figure 1. Glasses used to eliminate the participant's vision.

placement of COP_{ML} was determined by comparing a fixed window of 25 milliseconds before the stance transition to a moving window of the same length. An increase of more than 2 SDs on top of the mean baseline movement was identified as the onset of displacement of COP_{ML}, indicating the beginning of the transition from double-legged to single-legged stance.[21,38]

For the EMG data, the onset of muscle activity in reaction to the transition was determined. The raw EMG data were full-wave rectified and smoothed with a low-pass filter of 4 milliseconds with a zero-phase-lag, bidirectional (forward and backward), second-order Butterworth digital filter. A fixed window of 25 milliseconds before the stance transition was compared with a moving window of the same length. An increase of more than 2 SDs on top of the mean baseline activity was identified as the onset of muscle activity in reaction to the transition.[21,38] The sampling rate of the EMG signal was set at 2000 Hz, implying a time resolution of 0.5 milliseconds. This means that time intervals or durations theoretically can be measured with an accuracy of 1 millisecond. However, the latter error is increased by using a low-pass filter of 4 milliseconds. Therefore, the accuracy for determining the onset time is estimated at 10 milliseconds.

The onset of muscle activity determined by the computer was checked against the onset identified visually, according to the instructions by Hodges and Bui.[38] The onset of muscle activity was expressed relative to the onset of displacement of COP_{ML}, which was considered time zero. A negative value for the onset of muscle activity indicated an increase in muscle activity before the beginning of the transition. An example of the displacement of COP_{ML} and the onset of the peroneus longus muscle of 1 participant is shown in Figure 2.

We were interested in comparisons on the group level and the individual level. On the group level, the mean value and standard deviation of the onset time of muscle activity were calculated. This was done separately for trial 1 and trial 4, for both groups, and for the 3 conditions.

On the individual level, muscle activation patterns were determined. For each participant, muscles were ranked according to their onset times to determine the muscle recruitment order. The difference in onset times between 2 muscles had to exceed 10 milliseconds (measurement error) to represent a real difference. If the difference did not exceed 10 milliseconds, these muscles were considered to have an onset at the same time. The *muscle recruitment order* was defined as the region (ankle, knee, hip) where the muscles were recruited first.[21] Recruiting the ankle muscles first was called a *distal strategy;* recruiting the knee or hip muscles first was called a *proximal strategy*. However, if no single region of initial muscle recruitment could be distinguished or the difference in onset time between the ankle and knee or hip muscles did not exceed 10 milliseconds, the

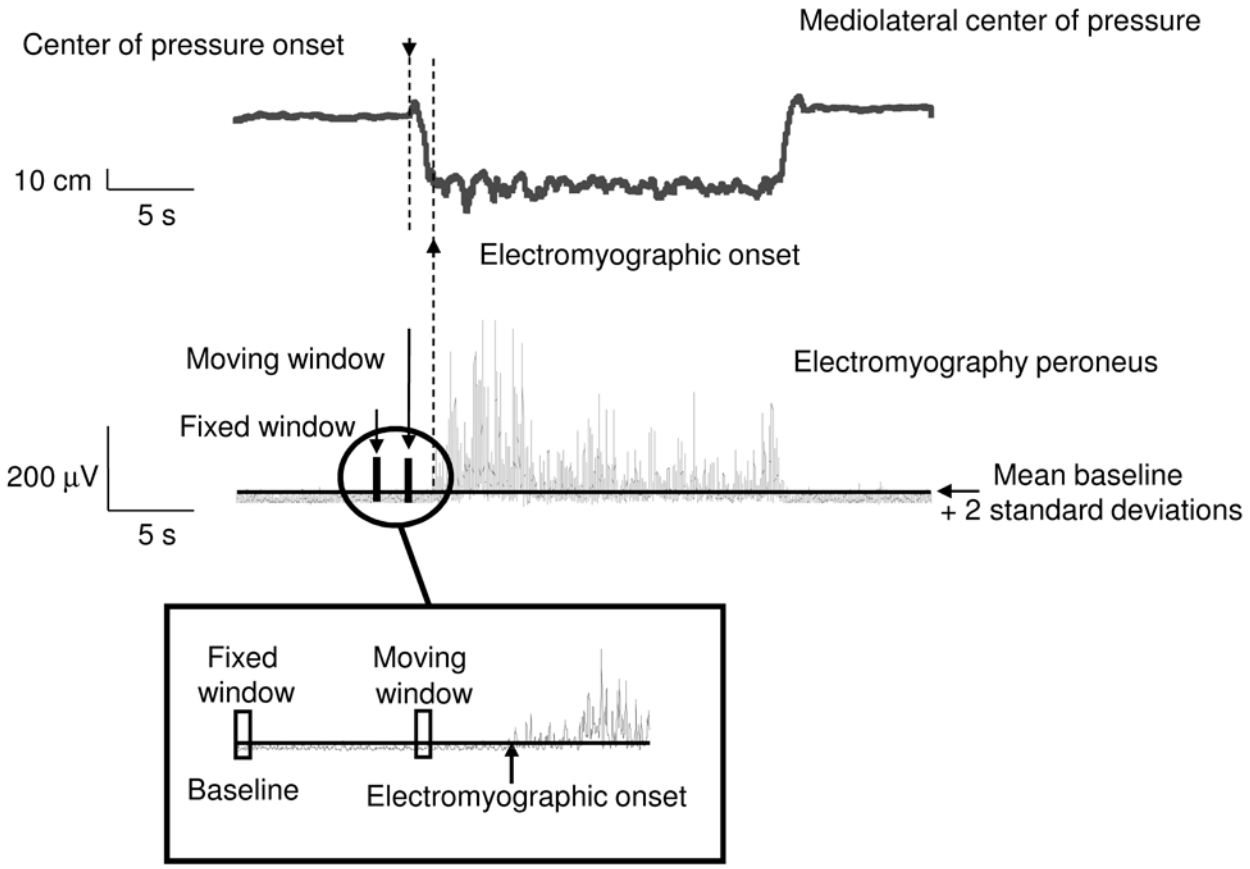

Figure 2. Displacement of the center of pressure in the mediolateral plane and activity of the peroneus longus muscle for 1 participant.

strategy was defined as a *mixed strategy*. Muscle recruitment order was defined for the vision, no-vision, and balance-pad conditions in both trials.

Statistical Analysis

On the group level, the group means of the onset time of muscle activity of trial 1 were compared with the group means of trial 4 using a 2-tailed *t* test ($\alpha = .05$). Three separate paired *t* tests (1 for each condition) were used to compare trial 1 and trial 4 for the control group. Three separate paired *t* tests also were used for the CAI group. Furthermore, agreement between the 2 repeated measurements was quantified using the difference between observations made on the same participant. The mean difference (d = trial 4 − trial 1), the standard error of the difference ($\sqrt{s^2/n}$), and the 95% limits of agreement were calculated.[40] These limits of agreement provide an interval within which 95% of the differences between the repeated measurements are expected to lie. The standard error of the difference provides information on the measurement error among trials and can serve as a reference for further research.

On the individual level, muscle activation patterns were compared between the first and the fourth trials. The percentage of agreement was calculated, and, when possible, the weighted κ (κw) with its 95% confidence interval was calculated. Linear weights were used for the calculation of κw. The interpretation of κw was based on the criteria of Landis and Koch.[41] A κw value less than 0.2 was considered to be slight; from 0.2 to 0.4, fair; from 0.41 to 0.6, moderate; from 0.61 to 0.8, substantial; and more than 0.8, almost perfect. Because prevalence of the attribute influences the κ coefficient, the prevalence index was calculated with the following formula:

$$\text{Prevalence index} = \frac{|a-d|}{n}$$

where a and d represent the cells of agreement and n represents the number of paired ratings.[42] The values ranged from 0 to 1. The prevalence index was designed for 2×2 tables. For this study, we worked with 3×3 tables, and the prevalence index was calculated for each pairwise comparison.[43] Only the highest prevalence value is reported. A high prevalence index reflects a high percentage of agreement and lowers the κ coefficient.[42] If the prevalence index was high (>0.70), no κw was calculated. The α level was set at .05. We used SAS software (version 9.1 for Windows; SAS Institute, Inc, Chicago, IL) and Excel 2007 (Microsoft Corporation, Redmond, WA) for statistical analysis.

RESULTS

Stability of the Measurements on the Group Level

The onset times of muscle activity for trial 1 and trial 4 (mean ± standard deviation) are presented for the vision condition in Table 1, for the no-vision condition in Table 2, and for the balance-pad condition in Table 3. Furthermore, the mean difference between trials, the standard error of the difference, the 95% limits of agreement, and the *P* values of the *t* tests are reported for each group.

Table 1. Onset Times of Muscle Activity for the Vision Condition

Muscle	Trial 1, s[a] (Mean ± SD)	Trial 4, s[a] (Mean ± SD)	*t*	*P*[b]	Mean Difference	Standard Error of the Difference	Lower and Upper Limits of Agreement
Control Group (n = 20)							
Peroneus longus	–0.17 (0.25)	–0.28 (0.2)	–2.79[c]	0.13	–0.10	0.04	–0.18, –0.03
Tibialis anterior	–0.29 (0.21)	–0.28 (0.2)	0.23[c]	0.9	0.008	0.04	–0.07, 0.08
Vastus medialis obliquus of the quadriceps femoris	–0.27 (0.29)	–0.24 (0.19)	0.37[d]	0.78	0.02	0.06	–0.10, 0.14
Vastus lateralis of the quadriceps femoris	–0.21 (0.4)	–0.29 (0.19)	–0.08[d]	0.45	–0.005	0.06	–0.14, 0.13
Tensor fasciae latae	–0.2 (0.24)	–0.19 (0.24)	–0.11[c]	0.9	0.03	0.06	–0.10, 0.15
Gluteus medius	–0.12 (0.15)	–0.09 (0.21)	0.93[d]	0.6	0.03	0.03	–0.03, 0.09
Gluteus maximus	0.01 (0.2)	–0.11 (0.24)	–4.21[c]	0.1	–0.12	0.03	–0.18, –0.06
Chronic Ankle Instability Group (n = 20)							
Peroneus longus	0.3 (0.39)	0.25 (0.26)	–0.29[c]	0.63	–0.10	0.07	–0.25, 0.05
Tibialis anterior	0.38 (0.48)	0.25 (0.43)	–1.10[c]	0.38	–0.05	0.09	–0.21, 0.16
Vastus medialis obliquus of the quadriceps femoris	0.03 (0.5)	–0.06 (0.31)	0.38[e]	0.52	0.17	0.09	–0.02, 0.36
Vastus lateralis of the quadriceps femoris	–0.09 (0.58)	–0.15 (0.42)	0.68[e]	0.75	0.09	0.12	–0.17, 0.35
Tensor fasciae latae	0.12 (0.54)	–0.01 (0.31)	4.33[c]	0.75	0.005	0.11	–0.23, 0.24
Gluteus medius	0.04 (0.25)	0.12 (0.15)	1.65[c]	0.2	0.09	0.05	–0.02, 0.20
Gluteus maximus	0.25 (0.22)	0.31 (0.4)	0.85[e]	0.6	0.075	0.08	–0.09, 0.24

[a] A negative value for the onset of muscle activity indicates an increase in muscle activity before the beginning of the transition.
[b] The α level was set at .05.
[c] Indicates df = 19.
[d] Indicates df = 18.
[e] Indicates df = 17.

Table 2. Onset Times of Muscle Activity for the No-Vision Condition

Muscle	Trial 1, s[a] (Mean ± SD)	Trial 4, s[a] (Mean ± SD)	*t*[b]	*P*[c]	Mean Difference	Standard Error of the Difference	Lower and Upper Limits of Agreement
Control Group (n = 20)							
Peroneus longus	–0.09 (0.42)	–0.17 (0.23)	–1.13	0.44	–0.15	0.03	–0.22, -0.08
Tibialis anterior	–0.14 (0.4)	–0.18 (0.22)	–0.47	0.74	–0.10	0.03	–0.17, -0.04
Vastus medialis obliquus of the quadriceps femoris	–0.11 (0.44)	–0.19 (0.41)	–0.94	0.56	–0.14	0.06	–0.24, 0.05
Vastus lateralis of the quadriceps femoris	–0.17 (0.47)	–0.16 (0.5)	–0.73	0.96	–0.11	0.07	–0.25, 0.03
Tensor fasciae latae	–0.1 (0.39)	–0.08 (0.43)	–1.43	0.52	–0.03	0.08	–0.19, 0.14
Gluteus medius	–0.13 (0.2)	–0.17 (0.2)	–1.03	0.53	–0.04	0.04	–0.12, 0.04
Gluteus maximus	0.04 (0.25)	–0.12 (0.25)	–4.11	0.08	–0.14	0.03	–0.21, –0.07
Chronic Ankle Instability Group (n = 20)							
Peroneus longus	0.5 (0.49)	0.48 (0.58)	0.30[b]	0.93	–0.03	0.11	–0.22, 0.26
Tibialis anterior	0.6 (0.5)	0.43 (0.45)	–1.45[b]	0.29	–0.11	0.10	–0.32, 0.10
Vastus medialis obliquus of the quadriceps femoris	0.24 (0.62)	0.19 (0.52)	–0.11[d]	0.8	0.07	0.09	–0.13, 0.27
Vastus lateralis of the quadriceps femoris	0.09 (0.71)	0.16 (0.56)	0.62[d]	0.76	0.20	0.06	0.07, 0.33
Tensor fasciae latae	0.31 (0.57)	0.43 (0.75)	3.25[b]	0.68	–0.005	0.09	–0.02, 0.19
Gluteus medius	0.16 (0.24)	0.23 (0.3)	1.56[b]	0.33	0.09	0.05	–0.03, 0.20
Gluteus maximus	0.32 (0.38)	0.54 (0.59)	1.35[e]	0.2	0.04	0.10	–0.16, 0.24

[a] A negative value for the onset of muscle activity indicates an increase in muscle activity before the beginning of the transition.
[b] Indicates df = 19.
[c] The α level was set at .05.
[d] Indicates df = 18.
[e] Indicates df = 17.

Table 3. Onset Times of Muscle Activity for the Balance-Pad Condition

Muscle	Trial 1, s[a] (Mean ± SD)	Trial 4, s[a] (Mean ± SD)	*t*	*P*[b]	Mean Difference	Standard Error of the Difference	Lower and Upper Limits of Agreement
			Control Group (n = 20)				
Peroneus longus	0.12 (0.33)	0.21 (0.34)	–1.41[c]	0.39	0.09	0.07	–0.05, 0.23
Tibialis anterior	0.11 (0.32)	0.22 (0.29)	1.39[c]	0.24	0.11	0.08	–0.06, 0.29
Vastus medialis obliquus of the quadriceps femoris	–0.2 (0.49)	–0.37 (0.48)	–1.59[d]	0.31	–0.11	0.06	–0.24, 0.02
Vastus lateralis of the quadriceps femoris	–0.34 (0.56)	–0.32 (0.67)	0.59[d]	0.95	–0.03	0.09	–0.23, 0.16
Tensor fasciae latae	–0.08 (0.49)	–0.17 (0.46)	–3.82[c]	0.07	–0.26	0.08	–0.41, 0.04
Gluteus medius	–0.12 (0.19)	–0.29 (0.34)	–3.52[c]	0.06	–0.17	0.05	–0.27, –0.07
Gluteus maximus	–0.01 (0.28)	–0.14 (0.35)	–3.08[c]	0.2	–0.14	0.04	–0.23, –0.04
			Chronic Ankle Instability Group (n = 20)				
Peroneus longus	0.46 (0.5)	0.47 (0.61)	0.06[c]	0.96	0.02	0.10	–0.18, 0.22
Tibialis anterior	0.48 (0.39)	0.37 (0.44)	–0.95[c]	0.44	–0.10	0.11	–0.33, 0.12
Vastus medialis obliquus of the quadriceps femoris	0.17 (0.46)	0.26 (0.33)	1.39[d]	0.51	0.097	0.09	–0.09, 0.28
Vastus lateralis of the quadriceps femoris	0.04 (0.61)	–0.16 (1.19)	0.23[d]	0.47	0.11	0.11	–0.12, 0.34
Tensor fasciae latae	0.29 (0.5)	0.23 (0.34)	3.18[c]	0.34	–0.004	0.08	–0.28, 0.04
Gluteus medius	0.09 (0.24)	0.18 (0.2)	1.46[c]	0.2	0.09	0.06	–0.04, 0.22
Gluteus maximus	0.31 (0.39)	0.49 (0.42)	1.31[c]	0.2	0.15	0.10	–0.06, 0.36

[a] A negative value for the onset of muscle activity indicates an increase in muscle activity before the beginning of the transition.
[b] The α level was set at .05.
[c] Indicates df = 19.
[d] Indicates df = 17.

The mean values of muscle onset times did not differ between trials 1 and 4. This was true for both groups and for each condition. In the control group, the mean difference ranged from –0.12 to 0.03 seconds for the vision condition (standard error of the difference range = 0.03 to 0.06 seconds), from –0.15 to –0.03 seconds for the no-vision condition (standard error of the difference range = 0.03 to 0.08 seconds), and from –0.26 to 0.11 seconds for the balance-pad condition (standard error of the difference range = 0.04 to 0.09 seconds). In the CAI group, the mean difference ranged from –0.10 to 0.17 seconds for the vision condition (standard error of the difference range = 0.05 to 0.12 seconds), from –0.11 to 0.20 seconds for the no-vision condition (standard error of the difference range = 0.05 to 0.11 seconds), and from –0.10 to 0.15 seconds for the balance-pad condition (standard error of the difference range = 0.06 to 0.11 seconds).

Stability of the Measurements on the Individual Level

The results for muscle recruitment order are given in Table 4 for the control group and in Table 5 for the CAI group. In the control group, the percentage of agreement ranged from 70% to 80% (Table 4). For the vision and no-vision condition, the κ_w was substantial and moderate, respectively. For the balance-pad condition, the prevalence index was greater than 0.70. In the CAI group, the percentage of agreement ranged from 75% to 90% (Table 5). No κ_w was calculated because of the high prevalence index.

DISCUSSION

On the group level, the results of the paired *t* tests showed no differences with regard to muscle activation onset time between trials 1 and 4, for both groups, or for the 3 conditions. This test was used to compare the means of the test and retest (ie, it tested whether any systematic bias existed between the tests). *Systematic bias* describes a general trend for measurements to be different in a particular direction (ie, due to a learning effect or due to insufficient recovery between tests).[44] Our results showed no systematic bias for muscle onset time. Furthermore, agreement between the repeated measurements was quantified using the difference between observations made on the same participant.

The method outlined in our study has been developed for use in intervention studies. Therefore, knowledge of measurement error is important for interpreting an individual's changes or differences.[44] In the literature, correlation coefficients often are used to investigate the reliability of results. However, correlation coefficients provide an indication of relative variability.[44] *Relative reliability* is the degree to which individuals maintain their position in a sample with repeated measurements and is influenced highly by the range of measured values. In contrast, *absolute reliability* is the degree to which repeated measurements vary for individuals and is unaffected by the range of measurements.[44] Therefore, absolute reliability provides an indication of variability in repeated tests for specific individuals, irrespective of where the individuals rank in a particular sample. The most common method of analyzing absolute reliability in the literature is the SEM. It assumes that a population of repeated measurements exists around a true value for each individual, that this population is normally distributed, and that no carryover effects exist when tests are repeated. Moreover, the SEM covers about 68% of the variability rather than 95%, which is the conventional criterion used in confidence interval comparisons.[44]

Bland and Altman[40] recognized several of these limitations

Table 4. Comparison of Muscle Recruitment Order Between Trial 1 and Trial 4 for the Control Group (n = 20)[a]

		Trial 4											
		Vision			No Vision			Balance Pad					
		Muscle Recruitment Pattern			Muscle Recruitment Pattern			Muscle Recruitment Pattern					
Trial 1	Muscle Recruitment Pattern	Proximal	Distal	Mixed	Proximal	Distal	Mixed	Proximal	Distal	Mixed	Agreement, %	Weighted κ (95% Confidence Interval)	Prevalence Index
Vision													
	Proximal	**4**	1	0							75	0.66 (0.53, 0.79)	0.05
	Distal	0	**6**	0									
	Mixed	1	3	**5**									
No vision													
	Proximal				**11**	0	5				70	0.49 (0.32, 0.67)	0.45
	Distal				1	**2**	0						
	Mixed				0	0	**1**						
Balance pad													
	Proximal							**16**	0	0	80	Not calculated	0.80
	Distal							0	**0**	0			
	Mixed							4	0	**0**			

[a] Bold indicates the number of participants who used the same recruitment pattern in both trials.

Table 5. Comparison of Muscle Recruitment Order Between Trial 1 and Trial 4 for the Chronic Ankle Instability Group (n = 20)[a]

		Trial 4											
		Vision			No Vision			Balance Pad					
		Muscle Recruitment Pattern			Muscle Recruitment Pattern			Muscle Recruitment Pattern					
Trial 1	Muscle Recruitment Pattern	Proximal	Distal	Mixed	Proximal	Distal	Mixed	Proximal	Distal	Mixed	Agreement, %	Weighted κ (95% Confidence Interval)	Prevalence Index
Vision													
	Proximal	**15**	1	3							75	Not calculated	0.75
	Distal	0	**0**	0									
	Mixed	1	0	**0**									
No vision													
	Proximal				**17**	1	1				90	Not calculated	0.89
	Distal				0	**0**	0						
	Mixed				0	0	**1**						
Balance pad													
	Proximal							**15**	0	5	75	Not calculated	0.75
	Distal							0	**0**	0			
	Mixed							0	0	**0**			

[a] Bold indicates the number of participants who used the same recruitment pattern in both trials.

with these different forms of analysis and introduced the method of limits of agreement, an indicator of absolute reliability similar to SEM. The main difference between these statistics seems to be that the limits of agreement assume a population of individual test-retest differences. These limits of agreement provide an interval within which 95% of the differences between the repeated measurements are expected to lie. Despite the superficial similarity, limits of agreement should not be interpreted as confidence intervals.[45] Whereas confidence intervals compare sample means to test for differences, limits of agreement provide a reference interval for the interpretation of individual test-retest differences. For example, for a new individual from the studied population, the difference due to measurement error between any 2 tests should lie within the limits of agreement (an approximate 95% probability).[44]

Therefore, for our purpose, it was more informative to have knowledge on the 95% limits of agreement based on mean differences between trials and standard errors of the differences (Tables 1–3). In the control group, the mean difference range was from −0.12 to 0.03 seconds for the vision condition (stan-

dard error of the difference range = 0.03 to 0.06 seconds), from −0.15 to −0.03 seconds for the no-vision condition (standard error of the difference range = 0.03 to 0.08 seconds), and from −0.26 to 0.11 seconds for the balance-pad condition (standard error of the difference range = 0.04 to 0.09 seconds). In the CAI group, the mean difference ranged from −0.10 to 0.17 seconds for the vision condition (standard error of the difference range = 0.05 to 0.12 seconds), from −0.11 to 0.20 seconds for the no-vision condition (standard error of the difference range = 0.05 to 0.11 seconds), and from −0.10 to 0.15 seconds for the balance-pad condition (standard error of the difference range = 0.06 to 0.11 seconds). This information indicates that, even within 1 session, variability of results can be expected between measurements. Given that the muscle activation for this task is not a reflex activity, the range of error is small.

This information can serve as a reference for further research. The standard error of the difference can be used to ascertain whether the difference in measurements between individuals or the change in measurements within an individual is real or due to measurement error.[44] Our results showed that the standard error of the difference was 0.09 seconds at maximum in control participants and 0.12 seconds in participants with CAI. When used for intervention studies, this means that the difference between the baseline measurement and the follow-up measurement should exceed 0.09 seconds in noninjured participants and 0.12 seconds in participants with CAI to represent real differences. When comparing muscle activation patterns between groups, the differences also should exceed the measurement error. Van Deun et al[21] demonstrated increased onset times for participants with CAI compared with noninjured participants. Because the differences between groups exceeded the standard error of the difference reported in our study, we can conclude that real differences, not merely measurement error, were measured.

With regard to the muscle recruitment order, the percentage of agreement ranged from 70% to 80% in the control group and from 75% to 90% in the CAI group. The high agreement could be attributed to the task itself. The postural-control strategy chosen by the central nervous system depends not only on the individual's goal, the environmental context, and the task the person is performing[46–51] but also on previous experience.[46,52] Participants in our study performed a transition task from a double-legged to a single-legged stance position. This weight-shifting task is known to the participants from daily life experience, resulting in a consistent control strategy.

In the literature, little research has been conducted on the stability of measurements with regard to muscle activation patterns. Comparisons are difficult to make because most of the researchers concentrated on sudden perturbations and used different variables than we used.[14,16,17]

CONCLUSIONS

Based on the data presented and research demonstrating changes in muscle activation patterns in CAI participants compared with noninjured participants,[21] we conclude that measurement stability for this task is acceptable for use in further research and that investigators can further consider the muscle activation patterns during voluntary perturbations. This is true for the 3 conditions and for both groups because we found no differences in measurement stability across conditions in both participant types.

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Address correspondence to Sara Van Deun, PhD, PT, Research Centre for Musculoskeletal Rehabilitation, Katholieke Universiteit Leuven, Tervuursevest 101, 3001 Leuven, Belgium. Address e-mail to sara.vandeun@faber.kuleuven.be.