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# Comparative Effects of Different Balance-Training–Progression Styles on Postural Control and Ankle Force Production: A Randomized Controlled Trial

Mutlu Cuğ, PhD*†; Ashley Duncan, BS†; Erik Wikstrom, PhD, ATC, FACSM‡

*Physical Education and Sports Department, Cumhuriyet University, Sivas, Turkey; †Department of Kinesiology, University of North Carolina at Charlotte; ‡Department of Exercise and Sport Science, University of North Carolina at Chapel Hill

***Context:*** Despite the effectiveness of balance training, the exact parameters needed to maximize the benefits of such programs remain unknown. One such factor is how individuals should progress to higher levels of task difficulty within a balance-training program. Yet no investigators have directly compared different balance-training–progression styles.

***Objective:*** To compare an error-based progression (ie, advance when proficient at a task) with a repetition-based progression (ie, advance after a set amount of repetitions) style during a balance-training program in healthy individuals.

***Design:*** Randomized controlled trial.

***Setting:*** Research laboratory.

***Patients or Other Participants:*** A total of 28 (16 women, 12 men) physically healthy young adults (age = 21.57 ± 3.95 years, height = 171.60 ± 11.03 cm, weight = 72.96 ± 16.18 kg, body mass index = 24.53 ± 3.7).

***Intervention(s):*** All participants completed 12 supervised balance-training sessions over 4 weeks. Each session consisted of a combination of dynamic unstable-surface tasks that incorporated a BOSU ball and lasted about 30 minutes.

***Main Outcome Measure(s):*** Static balance from an instrumented force plate, dynamic balance as measured via the Star Excursion Balance Test, and ankle force production in all 4 cardinal planes of motion as measured with a handheld dynamometer before and after the intervention.

***Results:*** Selected static postural-control outcomes, dynamic postural control, and ankle force production in all planes of motion improved ($P < .05$). However, no differences between the progression styles were observed ($P > .05$) for any of the outcome measures.

***Conclusions:*** A 4-week balance-training program consisting of dynamic unstable-surface exercises on a BOSU ball improved dynamic postural control and ankle force production in healthy young adults. These results suggest that an error-based balance-training program is comparable with but not superior to a repetition-based balance-training program in improving postural control and ankle force production in healthy young adults.

***Key Words:*** Star Excursion Balance Test, center of pressure, BOSU, ankle strength

**Key Points**

- Four weeks of balance training improved balance and ankle force production.
- Based on the small sample size, error-based and repetition-based balance-training–progression styles produced comparable results in healthy young adults.

Optimal control of balance in an upright stance is an essential requirement for sport, daily activities, and prevention of injury.[1] For example, impaired postural control is associated with an increased risk of ankle sprain.[2] Because of this strong association, balance and coordination training are common components of prophylactic and therapeutic intervention programs used by athletic trainers and other health care providers to treat patients with a variety of musculoskeletal conditions. Moreover, mounting evidence demonstrates that various balance-training programs improve postural control[3–6] and reduce the recurrence of musculoskeletal injuries (eg, ankle sprains).[2] Similarly, lower extremity force production improves after balance training in healthy young adults,[7,8] but conflicting evidence exists.[9,10] Research[11,12] in those with recurrent ankle sprains also demonstrated mixed results.

Despite the effectiveness of balance training in improving these outcomes, the exact parameters needed to maximize the benefits of balance-training programs remain unknown. One factor that has gained interest of late is the progression style. For example, participants or patients could be progressed to higher difficulty levels within a balance-training program after a set amount of time at a particular level (eg, 2 sessions or 8 repetitions). In contrast, participants or patients could be progressed only after they have demonstrated consistent movement proficiency. Some evidence suggests that balance improves when using a time-based or repetition-based–progression style.[5,7] According to the dynamic systems theory, an error-based progression style that evaluates consistent movement proficiency would allow the sensorimotor system to self-organize around a given set of task and environmental constraints before being challenged with greater demands at a higher difficulty level, which could result in a more

Table 1. Participants' Characteristics (Mean ± SD [Minimum–Maximum])

| | Group | |
|---|---|---|
| Characteristic | Error Based (n = 14; 5 men, 9 women) | Repetition Based (n = 14; 7 men, 7 women) |
| Age, y | 22.71 ± 5.12 (18–34) | 20.42 ± 1.87 (18–25) |
| Height, cm | 169.14 ± 10.10 (155–185) | 174.07 ± 11.73 (157–196) |
| Mass, kg | 68.85 ± 12.17 (52–88) | 77.07 ± 18.96 (45–102) |
| Body mass index | 23.95 ± 3.02 (20.32–30.86) | 25.11 ± 4.31 (18.26–33.91) |

profound improvement.[13] However, individual differences in the rate of self-organization and movement proficiency for a given task could vary significantly and thus may be a reason why this progression style has not been investigated empirically until recently. Indeed, several groups of researchers studying persons with chronic ankle instability (CAI) demonstrated that an error-based balance-training program was effective in improving postural control.[4,14,15] Yet no investigators have directly compared these balance-training–progression styles to determine if either produces better outcomes in postural control or ankle force production in any population.

Therefore, the purpose of our investigation was to compare the effectiveness of an error-based progression style with a repetition-based progression style during a balance-training program incorporating the BOSU ball (BOSU, Ashland, OH) in healthy individuals. Based on the existing literature, we hypothesized that both progression styles would significantly improve postural control and ankle force production. Using the dynamic systems theory of sensorimotor control as a framework, as well as data from previous investigations, we also hypothesized that the error-based progression style would have superior effects on the aforementioned outcomes.

## METHODS

### Participants

Twelve men (mean age = 22.5 ± 4.58 years, height = 181.58 ± 7.57 cm, weight = 85.25 ±10.67 kg, body mass index [BMI] = 25.87 ± 3.01) and 16 women (mean age = 20.87 ± 3.4 years, height = 164.13 ± 6.15 cm, weight = 63.75 ±13.3 kg, BMI = 23.53 ± 3.94) volunteered to participate in this study. Descriptive characteristics of the participants, as randomized into their training groups, are provided in Table 1. Inclusion criteria required that all participants be between the ages of 18 and 35 years and be *recreationally active*, which was operationally defined as performing at least 3 aerobic exercise sessions per week for at least 90 minutes. Additionally, participants must have been free from acute musculoskeletal injuries and concussions for at least 3 months before enrollment in the study; free from chronic musculoskeletal conditions; and free from visual, vestibular (eg, vertigo), or sensory conditions (eg, diabetes) that could negatively affect their postural control. Eligibility information was then collected with a questionnaire and follow-up interview before participants read and signed an approved informed consent form and reviewed the study's methods, possible side effects, and purpose with the research team, as approved by the university's ethics board, which also approved the study.

### Procedures

**Pretest and Posttest Assessments.** All test sessions consisted of assessing static and dynamic postural control and ankle force production. Strength testing was performed last during all test sessions to minimize the effects of fatigue. The research team was not blinded to group assignment, and all assessments were conducted in a quiet environment with no distractions.

***Static Balance.*** For the assessment of static postural control, all participants stood on an instrumented force plate (AMTI, Watertown, MA) in a single-limb stance (dominant limb only) with their hands on their hips, their nontested limb held above the force plate, and their eyes open. Testing was limited to the eyes-open condition because all training exercises were conducted with eyes open. In each of the three 10-second test trials, participants were asked to focus on a marker located at eye level on a wall 1 m away.[16] If, during a trial, participants touched down with their opposite limb or removed their hands from their hips, the trial was stopped and repeated until 3 successful assessments were completed. Ground reaction forces were collected at 50 Hz and filtered using a fourth-order, zero-lag, low-pass filter with a cutoff frequency of 5 Hz. The following outcomes were then calculated from the resulting center-of-pressure data: center-of-pressure velocity and 95% ellipse area. *Center-of-pressure velocity* is the total excursion of the center of pressure divided by the trial length; thus, it represents an average velocity throughout the static-stance trial. The *95% ellipse area* captures 95% of the data, as long as the data are normally distributed. These outcomes were calculated by AMTI's Balance Clinic software.

***Dynamic Postural Control.*** Participants also completed 3 test trials in 3 Star Excursion Balance Test (SEBT) reach directions (anterior, posteromedial, and posterolateral) on the dominant limb.[17] Research[17] has shown that these reach directions have the least redundancy among all of the SEBT reach directions. Before starting the SEBT test trials, each participant completed 6 practice trials per direction for familiarization and to reduce the known practice effect associated with the SEBT.[17]

For the reach trials, participants placed the test limb at the SEBT grid center using a toe-heel technique and kept their hands on their hips at all times. Participants then reached as far as possible in the 3 reach directions with their contralateral limb. The directional order was at the discretion of each individual. *Reach distance* was defined as the farthest point that an individual could touch without accepting weight on the reach limb and while maintaining balance through the return to the original bilateral-stance position.[17,18] All reach distances were normalized to the leg length (distance from the anterior-superior iliac spine to the ipsilateral medial malleolus) of the participant's dominant limb. The SEBT is a reliable measure of dynamic balance (intraclass correlation coefficient [2,1] = 0.85–0.96).[18] Reliability testing in our laboratory has indicated good to excellent intersession reliability (intraclass correlation coefficient [2,1] = 0.84–0.97). *Failed trials*, defined as a loss of balance or accepting weight on the reach limb, were eliminated and the task repeated until 3 successful trials in each direction were completed.

***Ankle Force Production.*** The musculature of the dominant ankle was tested isometrically using a MicroFET 2 (Hoggan Health Industries, Inc, Draper UT) handheld dynamometer as previously described.[19] Four muscle groups (dorsiflexors, plantar flexors, invertors, evertors) were tested by having participants ramp into a 3-second to 5-second maximal-effort contraction 3 times for each muscle group. Testing order was randomized among and within muscle groups and between efforts, and at least a 15-second rest period was given between contractions.[19] However, no warm-up or submaximal contractions, other than those needed to complete other assessment protocols, were completed before testing. For all muscle-strength tests, each participant was placed in a seated position with hips flexed and knees extended on a standard examination table. The dynamometer was positioned just distal to the base of the fifth metatarsal head for eversion, just proximal to the first metatarsal head for inversion, on the plantar aspect of the metatarsal heads for plantar flexion, and on the dorsum of the foot just proximal to the metatarsal heads for dorsiflexion. We chose a handheld dynamometer to quantify muscle force because it has fair to good intertester reliability[19] and, unlike isokinetic testing, can be used in a wide range of clinical settings. Reliability estimates (intraclass correlation coefficient [2,1]) from our laboratory suggest that dorsiflexion (0.66) and inversion are the least reliable measures (0.65), whereas eversion (0.73) and plantar flexion (0.82) are more stable measures. The maximum raw force value (N) produced during each of the 3 trials was then averaged across the trials. Verbal encouragement was given during each contraction.

**Balance-Training Intervention.** After baseline testing, participants were randomly assigned to 1 of 2 groups (an error-based balance-training group or a repetition-based balance-training group) in a 1 : 1 ratio. Randomization was performed using opaque, sealed envelopes that contained group assignments. These envelopes were created before the study by a member of the research team not involved in data collection. All available envelopes were presented to each participant for selection. All participants then underwent a total of 12 supervised training sessions, lasting about 30 minutes each over a 4-week period. The balance-training program used in the current investigation was a modification of the program initially described by McKeon et al[4] and is consistent with multiple investigations showing that a 4-week intervention is sufficient to observe postural-control improvements.[4–6,15] The following exercises were performed during each training session: (1) hop to stabilization onto and off a BOSU ball in 4 directions (anterior, lateral, anteromedial, and anterolateral), (2) mini squats on a BOSU ball while in a single-limb stance, (3) unanticipated reach sequences while stabilizing on a BOSU ball in a single-limb stance, and (4) static single-limb stance on a BOSU ball. A brief description of each exercise, the required number of repetitions per training session, and the progression of difficulty levels can be seen in the Appendix. The only difference between the groups was the way in which participants progressed from easier to more challenging levels of each balance task and in each direction within the balance tasks. In brief, participants in the repetition-based progression group moved to the next difficulty level after completing 2 training sessions, regardless of their task performance. Thus, participants in this group reached and performed exercises at level 6 during the 11th and 12th training sessions. Participants in the error-based progression group did not move to the next difficulty level until they completed an error-free set of repetitions (ie, a training session) for a particular task or a specific direction within a task in question. Therefore, it was possible for participants to remain at level 1 for the entire training program or to reach and perform exercises at level 12 during the last training session if they progressed through all of the previous training sessions without an error. The errors used to evaluate movement proficiency for each task are described in the Appendix. Participants returned for posttesting over the 2-day period immediately after completing the 12th training session.

## Statistical Analysis

Group demographics were compared using independent-samples *t* tests. Dynamic postural-control and force-production outcomes were then subjected to separate 2 × 2 multivariate analyses of variance (MANOVAs) to determine the effect of group (error or repetition) and time (pretest or posttest) as well as the interaction of the independent variables. Independent 2 × 2 analyses of variance (ANOVAs) were calculated to determine the effect of group (error or repetition) and time (pretest or posttest) as well as the interaction of the independent variables on static postural-control outcomes. Independent ANOVAs were conducted for the static postural-control outcomes because of weak intravariable correlations. An a priori $\alpha$ level of .05 identified statistical significance. Effect sizes and 95% confidence intervals (CIs) were then calculated to provide a measure of clinical meaningfulness. Between-groups effect sizes compared each group's pretest-to-posttest change score divided by each group's pooled standard deviation. Effect sizes were interpreted according to Cohen[20] (*small* = <0.4, *medium* = 0.41 to 0.7, *large* = >0.70).

## RESULTS

Demographic characteristics did not differ between the groups ($P > .05$). The 95% ellipse area ($F_{1,26} = 4.65$, $P = .04$) improved with a medium effect size relative to the baseline measure after the balance-training intervention (Table 2). Center-of-pressure velocity ($P = .20$) did not improve over time and was associated with a small effect size. Group differences ($P > .05$) and group × time interactions ($P > .05$) were not observed for either of the static postural-control variables. The overall MANOVA indicated that dynamic postural control improved as a result of the balance-training program ($P < .001$). Each SEBT reach distance also increased from pretest to posttest with medium (anterior) and large (posteromedial, posterolateral) effect sizes, as shown in Table 2. However, no group differences ($P = .72$) or group × time interactions ($P = .54$)

Table 2. Static Postural-Control, Dynamic Postural-Control, and Ankle Force-Production Results

| Variable | Group (Mean ± SD): Error Based, Pretest | Error Based, Posttest | Repetition Based, Pretest | Repetition Based, Posttest | Total, Pretest | Total, Posttest | Effect Size (95% Confidence Interval) |
|---|---|---|---|---|---|---|---|
| Static postural control | | | | | | | |
| Center-of-pressure velocity, cm/s | 3.70 ± 1.06 | 3.53 ± 0.81 | 3.61 ± 0.87 | 3.43 ± 0.59 | 3.66 ± 0.96 | 3.48 ± 0.70 | 0.27 (−0.26, 0.79) |
| 95% Ellipse area, cm | 6.19 ± 2.65 | 5.50 ± 1.83 | 5.84 ± 2.14 | 4.87 ± 1.59 | 6.03 ± 2.39 | 5.21 ± 1.72[a] | 0.52 (0.10, 1.06) |
| Dynamic postural control, % leg length | | | | | | | |
| Anterior | 68.62 ± 6.62 | 70.99 ± 7.04 | 66.89 ± 7.34 | 68.71 ± 6.50 | 67.75 ± 6.91 | 69.85 ± 6.75[a] | 0.64 (0.10, 1.18) |
| Posteromedial | 83.95 ± 7.39 | 88.36 ± 8.07 | 84.92 ± 7.32 | 87.83 ± 6.92 | 84.43 ± 7.23 | 88.09 ± 7.37[a] | 0.73 (0.19, 1.27) |
| Posterolateral | 78.50 ± 9.25 | 83.75 ± 10.31 | 80.05 ± 7.36 | 84.69 ± 7.44 | 79.27 ± 8.24 | 84.21 ± 8.83[a] | 1.09 (0.53, 1.65) |
| Ankle force production, N | | | | | | | |
| Plantar flexion | 250.25 ± 43.63 | 296.56 ± 58.80 | 277.20 ± 59.69 | 310.44 ± 75.13 | 263.95 ± 53.15 | 303.45 ± 66.54[a] | 0.80 (0.25, 1.34) |
| Dorsiflexion | 165.20 ± 33.93 | 196.03 ± 33.71 | 184.69 ± 54.26 | 217.87 ± 70.68 | 174.94 ± 45.50 | 206.93 ± 55.42[a] | 0.75 (0.21, 1.29) |
| Inversion | 79.84 ± 22.06 | 99.23 ± 27.57 | 90.56 ± 32.78 | 109.07 ± 39.9 | 85.18 ± 27.93 | 104.13 ± 34.02[a] | 1.10 (0.54, 1.14) |
| Eversion | 82.6 ± 22.24 | 101.24 ± 17.12 | 90.43 ± 29.26 | 105.15 ± 32.20 | 86.51 ± 25.79 | 103.19 ± 25.35[a] | 1.02 (0.46, 1.57) |

[a] Indicates difference ($P < .05$).

were noted for dynamic postural control. Similarly, the overall MANOVA revealed that ankle force production increased from pretest to posttest ($F_{4,23} = 14.66$, $P < .001$). Each ankle motion resulted in increased force production after the balance-training intervention with medium (dorsiflexion) and large (plantar flexion, inversion, eversion) effect sizes (Table 2). Force production did not differ between the groups ($P = .99$) and no group × time interaction ($P = .91$) was evident. Between-groups effect sizes were small, and all 95% CIs crossed zero, as illustrated in Figure 1.

## DISCUSSION

The purpose of our project was to compare an error-based (proficiency) progression style with a repetition-based progression style during a BOSU ball balance-training program in healthy individuals. We hypothesized that (1) both progression styles would improve postural control and ankle force production and (2) an error-based progression style would have superior effects on the aforementioned outcomes. The results of this investigation partially supported our a priori hypotheses, as both groups showed improvements in ankle force production (all planes) and dynamic balance (all directions). However, only one of the static postural-control measures improved. These findings are consistent with those of previous authors who examined the effects of balance training on static postural control,[4,6] dynamic postural control,[3,6] and ankle force production[8] in healthy individuals. However, no differences were observed between the error-based and repetition-based progression styles in our sample of healthy young adults.

### Postural Control

Evidence suggests that balance-training programs of short to moderate duration over the course of at least 4 weeks can improve objective and subjective measures of function in persons with musculoskeletal injuries (eg, CAI)[4,14,15] and uninjured control participants.[5,6] For example, a systematic review by Zech et al[6] demonstrated an overall effect size of 0.43 (0.05 to 0.80) for postural-sway improvements in healthy adults after completing balance-training programs of various lengths. Researchers of the 4-week balance-training programs included in the systematic review also reported individual effect sizes and 95% CIs (eg, 0.42 [–0.18 to 1.02],[21] –0.48 [0.30 to –1.48],[22] 0.25 [–0.09 to 0.30],[23] and 0.65 [–0.03 to 1.32][24]) consistent with the static postural-control effect sizes observed in our total sample. Similarly, Rothermel et al[5] reported an improvement in center-of-pressure velocity after a 4-week balance-training program in healthy young adults. In the current investigation, we observed static postural-control improvements in the 95% ellipse area but not in center-of-pressure velocity. Differences, particularly in center-of-pressure velocity, may be due to the type of exercises (static versus dynamic) or training parameters (or both) between the investigations. Using an error-based progressive style, 4-week balance-training programs including a combination of low-impact and dynamic activities have also improved self-assessed disability and postural control in those with CAI.[4] McKeon et al[4] observed SEBT improvements in the posteromedial- and posterolateral-reach directions, whereas Schaefer et al,[15] who used the same balance-training

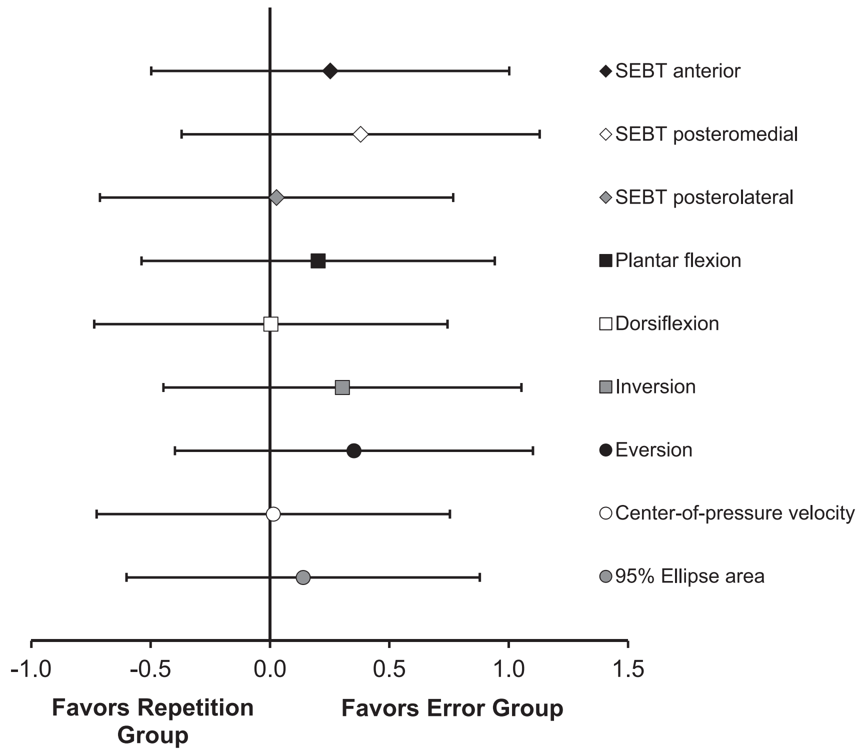


**Figure 1. Forrest plot demonstrating the between-groups effect sizes calculated from the pretest-to-posttest change scores for each of the dependent variables and their 95% confidence intervals. Abbreviation: SEBT, Star Excursion Balance Test.**

program, demonstrated SEBT improvements in the anterior-reach direction in those with CAI. Hilgendorf et al[14] used a similar error-based progression style and reported an effect size of 1.93 (0.75 to 3.12), signifying large improvements in the Overall Stability Index outcome in those with CAI. A large effect size for the total SEBT reach distance (3.58 [95% CI = 2.37–4.78]) has been reported after a 4-week balance-training program in healthy adults.[25] These improvements are larger than those we observed, where SEBT effect sizes ranged from 0.64 to 1.09. The larger effect sizes observed in those with CAI may be due to the sensorimotor deficits and dynamic postural-control impairments that were present in the CAI sample and absent in our sample of uninjured healthy controls. Differences between the findings of the current investigation and those of Rasool and George[25] are likely due to differences in balance-training exercises and volume of training. Although both programs lasted 4 weeks, Rasool and George[25] had participants train 5 days a week for 60 minutes a day, whereas we required 3 training sessions a week, each lasting about 30 minutes.

## Force Production

Repetition-based progression styles have also improved leg-extensor strength and jumping height in adolescents after 4 weeks of balance training (12 training sessions) in addition to postural control.[26] Heitkamp et al[8] also demonstrated that 12 balance-training sessions over 6 weeks improved quadriceps and hamstrings strength in healthy individuals. Six weeks of unstable-surface training on a wobble board improved ankle dorsiflexion (effect size = 2.19 [95% CI = 1.31 to 3.06]) and plantar flexion (effect size = 1.66 [95% CI = 0.85 to 2.46]) when measured with a cable tensiometer in healthy young men.[7] Differences between previous research and the current study may be due to the assessment tools (cable tensiometer versus handheld dynomometer). Unfortunately, the effects of an error-based progression style on muscular strength or force production (or both) after a balance-training program have not been evaluated, making it difficult to place the results of this investigation within the context of the literature. Several potential reasons may explain why gains in force production are observed after balance-training protocols. Balance training, especially when performed on unstable surfaces, increases muscle activation and helps improve synergist coordination, agonist-antagonist timing, stabilizer function, and motor-unit recruitment. These neuromuscular alterations are thought to better stabilize the center of mass with a stable or changing base of support or while transitioning from a dynamic to a static state.[27] These neuromuscular adaptations help maintain postural control and could also improve muscular force during isometric testing.[28] Additionally, several of the exercises in the current study required eccentric loading as well as aspects, landing, and amortization similar to those of plyometric training. Both eccentric contractions[29] and plyometric training[30] improved isometric and maximal force production due to adaptations in the neural system, such as increased motor-unit firing frequency, improved motor-unit synchronization, and increased motor-unit excitability and efferent motor drive.[31]

## Progression Style

In theory, an error-based progression model (ie, one ensuring basic movement proficiency before increasing task difficulty) should improve the sensorimotor system's ability to adapt to changing task and environmental constraints

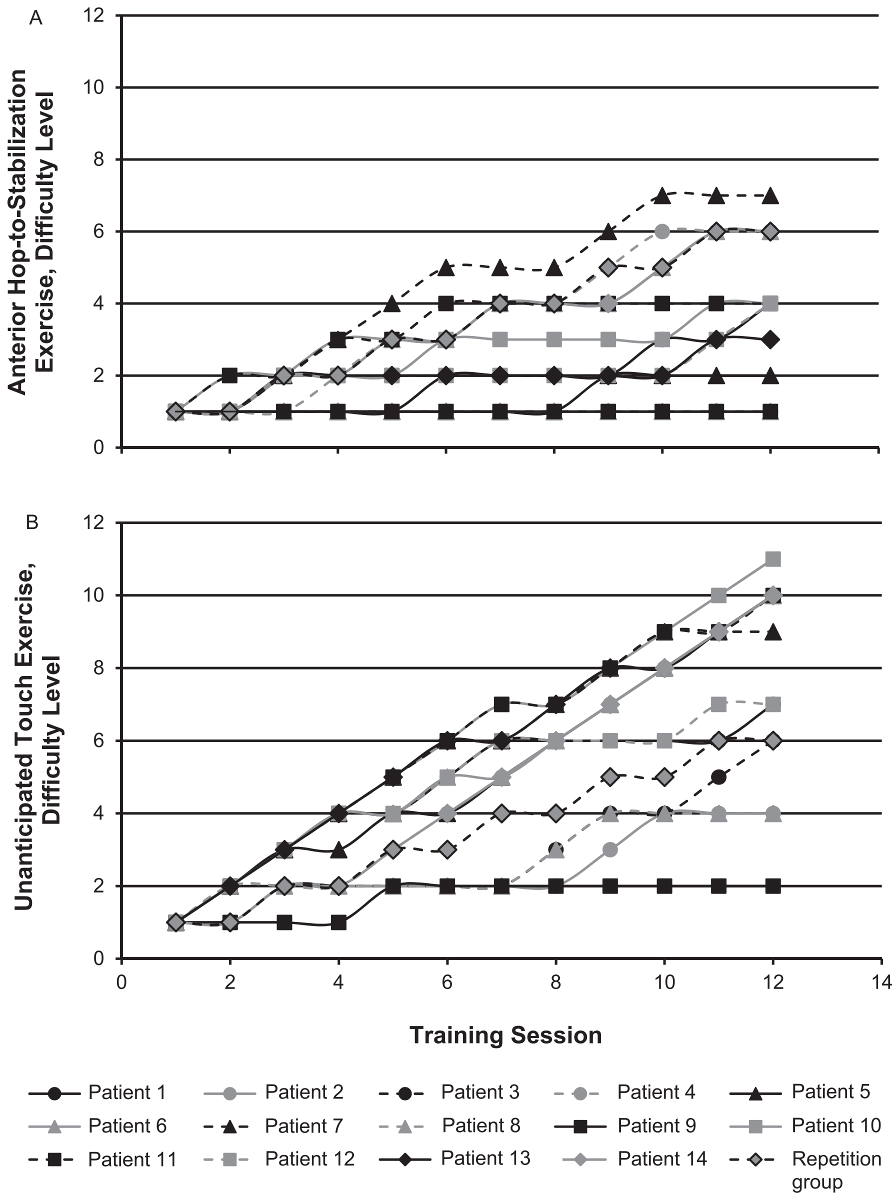


**Figure 2. Improvement for each patient in the error-based group and the progression of the repetition-based group for the following exercises. A, The anterior hop-to-stabilization exercise. B, The unanticipated-touch exercise over time.**

better than progressing a person simply because of the time spent performing a task. Thus, not all individuals in an error-based balance-training program would be expected to progress as far or at the same rate, with regard to the level of task difficulty achieved, as those in a repetition-based group. The magnitude and rate of progression in our error-based group support this notion and can be seen in Figure 2.

Despite participants progressing in the manner expected, the results did not indicate that an error-based progression model was superior to a repetition-based progression model in uninjured, healthy young adults. Several explanations are possible. First, the training parameters (eg, duration, frequency, intensity) may not have been large enough to elicit differences, or the outcome measures may not have been sensitive enough to detect differences. The unconstrained sensorimotor systems of our small sample of healthy young adults might have hindered our ability to observe improvements in the error-based progression group relative to the repetition-based progression group. Previous error-based balance-training programs in those with CAI have all shown meaningful pretest-to-posttest improvements,[4,14,15] most likely due to the sensorimotor constraints in this patient population that would allow for greater improvements over time. However, no investigators have directly compared the effectiveness of error-based versus repetition-based progression styles in those with CAI.

Therefore, future researchers need to assess the effectiveness of an error-based progression style relative to a repetition-based progression style in larger sample sizes of various patient populations with known sensorimotor constraints. Future authors should also incorporate an impairment-based model[32] to determine the starting level for each participant, regardless of the progression style used. An impairment-based model stresses the importance of personalized medicine and attempts to link patient-specific deficits with optimal interventions. Data from our investiga-

**Table 3. Errors Made by the Repetition-Based and Error-Based Progression Groups Across All Training Sessions for the Hop-to-Stabilization Task in the Anterior-Posterior Direction and the Unanticipated-Touch Exercise (Mean ± SD)**

| Task or Exercise | Training Session | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Hop to stabilization | | | | | | | | | | | | |
| Error-based group | 3.43 ± 2.10 | 1.86 ± 2.07 | 2.07 ± 2.09 | 1.86 ± 2.35 | 2.00 ± 1.96 | 1.86 ± 1.70 | 1.71 ± 1.68 | 2.07 ± 1.69 | 1.43 ± 1.87 | 1.64 ± 1.82 | 1.50 ± 2.10 | 1.93 ± 1.90 |
| Repetition-based group | 4.00 ± 1.88 | 3.29 ± 1.86 | 3.00 ± 1.75 | 2.93 ± 1.86 | 3.07 ± 2.27 | 2.50 ± 1.65 | 2.93 ± 1.64 | 3.14 ± 1.66 | 2.86 ± 2.03 | 2.79 ± 2.03 | 2.86 ± 2.32 | 2.50 ± 2.03 |
| Unanticipated touch | | | | | | | | | | | | |
| Error-based group | 0.77 ± 1.69 | 0.69 ± 1.55 | 1.23 ± 1.64 | 0.92 ± 1.19 | 1.38 ± 2.06 | 1.23 ± 1.54 | 1.00 ± 1.47 | 0.77 ± 1.59 | 1.08 ± 1.38 | 0.77 ± 1.66 | 0.69 ± 1.44 | 0.46 ± 0.66 |
| Repetition-based group | 0.50 ± 0.94 | 0.93 ± 1.82 | 1.79 ± 1.93 | 1.14 ± 1.79 | 0.21 ± 0.58 | 0.36 ± 0.93 | 0.86 ± 0.95 | 0.36 ± 0.63 | 0.21 ± 0.58 | 0.29 ± 0.61 | 1.00 ± 1.24 | 0.79 ± 1.31 |

tion support the use of an impairment-based model in future research, as several of the participants in the error-based progression group progressed each session without reaching a plateau during the first half of the intervention (Figure 2). This trend suggests that the lower exercise-difficulty levels failed to sufficiently challenge the postural-control systems of these individuals. Similarly, several participants progressed only 1 or 2 levels throughout the entire study (Figure 2), indicating that even the lower exercise-difficulty levels were too difficult for some participants and therefore may not have allowed them to develop better self-organization behaviors. Data from the repetition-based progression group also support the need to consider an impairment-based model when initiating a balance-training program. Those in the repetition-based progression group appeared to have greater difficulty with the preset difficulty levels in some exercises while having little trouble in others (Table 3), which illustrates the need to start each participant at a difficulty level appropriate for his or her ability. Although challenging from a research perspective, evaluating individual patient-specific deficits[32] to ensure an appropriate starting difficulty level will allow all participants to start a balance-training program at a level that challenges their postural-control system (eg, a level at which they may make 1 or 2 errors during a 10-trial set) and perhaps better elucidate the true benefits of various balance-training interventions.

We chose a small sample of healthy young adults in part to estimate realistic sample sizes for future research with various patient populations. The overall between-groups effect sizes derived from pretest-to-posttest change scores suggest that an error-based balance-training program may be more effective. This is based on the fact that 67% of the dependent variable point estimates clearly favor the error-based progression group compared with the 0.0% that clearly favor the repetition-based progression group. However, all 95% CIs cross zero (Figure 1). Thus, when the effectiveness of an error-based versus repetition-based balance-training program is examined in a larger group with constrained sensorimotor systems, we hypothesize that the error-based style would result in larger effect sizes with 95% CIs that do not cross zero. Using the between-groups effect sizes based on pretest-to-posttest change scores, an $\alpha$ level of .05, and $1-\beta$ set at 0.80, we calculated the total number of participants needed to detect a statistically significant difference between an error-based and repetition-based progression style. Using just the posteromedial-reach direction of the SEBT, a total of 36 participants would be needed to detect group differences, whereas 104 participants would be needed if the average effect size of all the SEBT outcomes was used. Using just the eversion-strength effect size, a total of 44 participants would be needed, whereas 112 participants would be needed based on the average effect size of all strength outcomes.

The current investigation, like others, is not without limitations. Most notably, the small sample size may have resulted in the study being underpowered. The health status of the sample and duration of the training program may have also limited our ability to detect the true effects of an error-based progression style. For example, in their systematic review, Zech et al[6] found that balance-training programs lasting 4 weeks had small and smaller effects, respectively, on postural-sway and functional-balance measures (eg, the SEBT) than did programs of 6 weeks and longer. However, it should be noted that our between-groups effect sizes for dynamic postural control and ankle force production were comparable with the effect sizes reported previously. Thus, future researchers should consider not only larger sample sizes but also longer-duration training programs to ensure the presence of notable adaptations in sensorimotor control that can demonstrate between-groups differences.[6] Another limitation is the fact that the assessors were not blinded to group allocation. However, we used a valid and reliable measure of postural control and an objective measure of force production to minimize the potential for bias.

## CONCLUSIONS

A 4-week balance-training program consisting of dynamic unstable-surface exercises on a BOSU ball improved dynamic postural control, ankle force production, and aspects of static postural control in healthy young adults. Based on these results, an error-based progression style would appear to be comparable with but not superior to a repetition-based progression style in improving postural control and ankle force production in healthy young adults.

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## Appendix. Exercise Descriptions

## EXERCISES

### Hop to Stabilization Onto a BOSU Ball

Participants hop onto a BOSU (BOSU, Ashland, OH) ball placed at a target distance away (45.72, 68.58, and 91.44 cm), stabilize, hop back to the starting position, and stabilize. Hops are performed in 4 directions: anterior-posterior, medial-lateral, anterolateral-posteromedial, and anteromedial-posterolateral. In each direction, participants are instructed to perform 6 jumps during each training session.

### Squat on a BOSU Ball

Participants stabilize on a BOSU ball and perform a single-legged squat to a target depth and within a predetermined time frame (5 seconds). Six trials are performed during each session.

### Unanticipated Reach While Stabilizing on a BOSU Ball

Participants stabilize on a BOSU ball that is centered in the middle of a 9-marker grid (individually numbered) and reach to the randomly presented target number with the nonstance limb. Participants can use any reach style as long as they reach the target within a designated time frame. Six sequences are performed per training session.

### Single-Limb–Stance Balance

Participants complete a single-limb–stance exercise with eyes open. Six trials are performed during each session.

**Appendix Table. Description of Errors Associated With Balance-Training Exercises**

| Hop to Stabilization | Unanticipated Reach | Squat | Single-Limb Stance |
|---|---|---|---|
| Touching down with the opposite limb | Touching down with the opposite limb | Touching down with the opposite limb | Touching down with the opposite limb |
| Excessive trunk motion (>30° of lateral flexion) | Excessive trunk motion (>30° of lateral flexion) | Excessive trunk motion (>30° of lateral flexion) | Excessive trunk motion (>30° of lateral flexion) |
| Bracing nonstance limb against stance limb | Bracing nonstance limb against stance limb | Bracing nonstance limb against stance limb | Bracing nonstance limb against stance limb |
| Not meeting the time requirement | Not meeting the time requirement | Not meeting the time requirement | |
| Missing the target | Missing the target | | |
| Removing hands from the target area during appropriate activities | Removing hands from the target area | Removing hands from the target area | Removing hands from the target area |
| | Using the reach limb for a substantial amount of support during the reach component | | |

## Error Criteria for Exercises (see the Appendix Table)

## PROGRESSIONS

### Repetition-Based Group

Participants complete the exercises described (and set repetitions) during each training session. They progress to the next difficulty level for each exercise after 2 training sessions. Thus, at the end of the training program, each participant in the repetition-based group performs all exercises at level 6.

### Error-Based Group

Participants complete the exercises described (and set repetitions) during each training session. Progression to higher difficulty levels for each exercise is achieved independently by demonstrating movement profiency (ie, error-free performance). Activity-specific errors include touching down with the opposite limb, excessive trunk motion, removing hands from hips, bracing the nonstance limb against the stance limb, and missing a target. To progress, a participant must perform all 6 repetitions of each exercise within a given training session without error. Therefore, it is possible for participants to reach and perform exercises at level 12 if they progress through all of the previous training sessions without an error.

## LEVEL DESCRIPTION

**Single-Limb Hops to Stabilization Onto a BOSU Ball**

1. The 45.72-cm hop: Participants are allowed to use the upper extremities to aid in stabilizing balance after landing.
2. The 45.72-cm hop: Participants keep hands on the hips while stabilizing balance after landing.
3. The 68.58-cm hop: Participants are allowed to use the upper extremities to aid in stabilizing balance after landing.
4. The 68.58-cm hop: Participants keep hands on the hips while stabilizing balance after landing.
5. The 91.44-cm hop: Participants are allowed to use upper extremities to aid in stabilizing balance after landing.
6. The 91.44-cm hop: Participants keep hands on the hips while stabilizing balance after landing.
7. The 91.44-cm hop: Participants perform 3 back-to-back jumps (and are allowed to use the upper extremities).
8. The 91.44-cm hop: Participants perform 3 back-to-back jumps (and are not allowed to use the upper extremities).
9. The 91.44-cm hop: Participants perform 6 back-to-back jumps from 91.44 cm (and are allowed to use the upper extremities).
10. The 91.44-cm hop: Participants perform 6 back-to-back jumps (and are not allowed to use the upper extremities).
11. The 91.44-cm hop: Participants perform 6 back-to-back jumps without waiting between jumps (and are allowed to use the upper extremities).
12. The 91.44-cm hop: Participants perform 6 back-to-back jumps without waiting between jumps (and are not allowed to use the upper extremities).

**Stabilization and Unanticipated Reach (Hands on Hips for Levels 1–6)**

1. Participants take 5 seconds per move while standing on a hard surface.
2. Participants take 5 seconds per move while standing on a dome.
3. Participants take 3 seconds per move while standing on a hard surface.
4. Participants take 3 seconds per move while standing on a dome.
5. Participants take 3 seconds per move while standing on a hard surface and with 2 cones at altered heights.
6. Participants take 3 seconds per move while standing on a dome and with 2 cones at altered heights.
7. Participants take 3 seconds per move while standing on a hard surface and with 2 cones at altered heights and 1 cone farther away.
8. Participants take 3 seconds per move while standing on a dome and with 2 cones at altered heights and 1 cone farther away.
9. Participants take 3 seconds per move while standing on a hard surface and with 2 cones at altered heights and 2 cones farther away.
10. Participants take 3 seconds per move while standing on a dome and with 2 cones at altered heights and 2 cones farther away.
11. Participants take 3 seconds per move while standing on a hard surface and with 2 cones at altered heights and 3 cones farther away.
12. Participants take 3 seconds per move while standing on a dome and with 2 cones at altered heights and 3 cones farther away.

**Squat on a BOSU Ball (Hands on Hips for Levels 1–6)**

1. Single-limb squat to 30° and return to stabilized position within 5 seconds while on a hard surface.
2. Single-limb squat to 30° and return to stabilized position within 5 seconds while on a dome.
3. Single-limb squat to 60° and return to stabilized position within 5 seconds while on a hard surface.
4. Single-limb squat to 60° and return to stabilized position within 5 seconds while on a dome.
5. Single-limb squat to 90° and return to stabilized position within 5 seconds while on a hard surface.
6. Single-limb squat to 90° and return to stabilized position within 5 seconds while on a dome.
7. Single-limb squat to 90° and return to stabilized position within 5 seconds while on a hard surface and 1 ball toss (going down catch, going up throw).
8. Single-limb squat to 90° and return to stabilized position within 5 seconds while on a dome and 1 ball toss (going down catch, going up throw).
9. Single-limb squat to 90° and return to stabilized position within 5 seconds while on a hard surface and 2 ball tosses (1 going down, 1 going up).
10. Single-limb squat to 90° and return to stabilized position within 5 seconds while on a dome and 2 ball tosses (1 going down, 1 going up).
11. Single-limb squat to 90° and return to stabilized position within 5 seconds while on a hard surface and 3 ball tosses (1 going down, 1 deeper level, 1 going up).
12. Single-limb squat to 90° and return to stabilized position within 5 seconds while on a dome and 3 ball tosses (1 going down, 1 deeper level, 1 going up).

**Single-Limb Stance (Hands on Hips for Levels 1–6; Eyes Open for All Levels)**

1. Stand on a hard surface for 30 seconds.
2. Stand on a dome for 30 seconds.
3. Stand on a hard surface for 60 seconds.
4. Stand on a dome for 60 seconds.
5. Stand on a hard surface for 90 seconds.
6. Stand on a dome for 90 seconds.
7. Stand on a hard surface for 90 seconds with upper extremities across chest.
8. Stand on a dome for 90 seconds with upper extremities across chest.
9. Stand on a hard surface for 90 seconds and perform a ball toss every 15 seconds.
10. Stand on a dome for 90 seconds and perform a ball toss every 15 seconds.
11. Stand on a hard surface for 90 seconds and perform a ball toss every 10 seconds.
12. Stand on a dome for 90 seconds and perform a ball toss every 10 seconds.

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*Address correspondence to Mutlu Cuğ, PhD, Physical Education and Sports Department, Cumhuriyet University, Sivas, 58130, Turkey. Address e-mail to mutlucug@gmail.com.*