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Original research

Predicting dynamic balance improvements following 4-weeks of balance training in chronic ankle instability patients

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ABSTRACT

Objectives: Balance training typically features as a central component of exercise-based rehabilitation programs for patients with lateral ankle sprain and chronic ankle instability (CAI). The purpose of this study was to conduct a responder/non-responder analysis using existing data to identify factors associated with improvements in dynamic balance performance in CAI patients.
Design: Secondary data analysis.
Methods: Data was used from 73 CAI patients who participated in 6 previous investigations that used the same balance training program. We defined treatment success as a patient exceeding the minimal detectable change score (8.15%) for the posteriomedial direction of the Star Excursion Balance Test (SEBT-PM). Baseline measures of participant and injury demographics, patient-reported function, and dynamic balance were entered into a step-wise logistic regression model to determine the best set of predictors of treatment success.
Results: Only 28 out of 73 patients (38.4%) demonstrated a successful improvement in SEBT-PM reach after balance training. Of the variables assessed, SEBT-PM reach distance ≤85.18% and self-reported function activities of daily living score ≤92.55% were significant predictors of treatment success ($p < 0.001$). If a patient met both these criteria there was a 70% probability of a successful treatment, indicating a 31.6% increase in the probability of a meaningful balance improvement after completing balance training.
Conclusions: Without screening, less than 40% of CAI patients experience a meaningful improvement in SEBT-PM following balance training. Completing a brief pre-treatment assessment of a patient- and clinician-oriented outcome can significantly improve the probability of determining patients with CAI who may improve dynamic balance after balance training.

Practical implications

- Not all patients with ankle instability will improve balance after balance training.
- A quick, multifaceted pre-treatment screening can improve the likelihood of a successful improvement in balance after balance training.
- Poor dynamic balance is the strongest individual predictor of a successful improvement in balance.

While often considered an innocuous injury, a lateral ankle sprain is one of the most common musculoskeletal injuries, accounting for up to 20% of injuries sustained during organized sports.[1,2] Recent data suggests approximately 40% of individuals who sustain a lateral ankle sprain will develop chronic ankle instability (CAI).[3] CAI is characterized by persistent complaints of the ankle giving way or rolling, as well as recurrent ankle sprains and/or mechanical laxity of the joint.[4] Individuals with CAI often

Abbreviations: CAI, chronic ankle instability; SEBT, Star Excursion Balance Test; MDC, minimal detectable change; CPR, clinical prediction rule; FAAM, foot and ankle ability measure; FADI, foot and ankle disability index.

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Table 1
Inclusion and exclusion criteria for included studies and the number of participants from each study used.

Study	Sample Size	Criteria	
McKeon et al.[12]	15	Inclusion	≥4 answers of "Yes" on AII[a], ≤90% on FADI[b] and FADI-Sport
		Exclusion	Acute injury (≤6 weeks), lower extremity surgery, history of balance disorders, diabetes, or neuropathy.
Schaefer and Sandrey[13]	9	Inclusion	≥4 answers of "Yes" on AII
		Exclusion	No history of ankle sprain or perceived giving way, grade III ankle laxity (anterior drawer, talar tilt, medial subtalar glide), lower extremity surgery, history of balance disorders, diabetes, or neuropathy.
Burcal et al.[14]	12	Inclusion	≥4 answers of "Yes" on AII, ≤90% on FAAM[c], ≤80% on FAAM-S[d]
		Exclusion	Acute injury (≤6 weeks), lower extremity surgery, history of balance disorders, vision problems.
Anguish and Sandrey[20]	11	Inclusion	≥4 answers of "Yes" on AII
		Exclusion	No history of lower extremity surgery, history of balance disorders, diabetes, or neuropathy.
Burcal et al.[21]	15	Inclusion	Score ≥11 on IdFAI[e]
		Exclusion	Acute injury (≤6 weeks), lower extremity surgery, history of balance disorders, diabetes, neuropathy, concussion.
Gonzales[22]	11	Inclusion	≥5 answers of "Yes" on AII, ≤90% on FAAM ≤80% on FAAM-S
		Exclusion	Acute injury (≤12 weeks), lower extremity surgery, history of concussion, neural impairments, lower limb fractures.

[a] Ankle Instability Instrument.
[b] Foot and Ankle Disability Index.
[c] Foot and Ankle Ability Measure.
[d] Foot and Ankle Ability Measure Sport Scale.
[e] Identification of Functional Ankle Instability.

report lower health-related quality of life[5] and decreased physical activity levels relative to their uninjured peers.[6] Functionally, CAI patients exhibit postural control impairments across a spectrum of tasks including static balance, dynamic balance, and gait.[7,8] These impairments are thought to contribute to the continuum of disability experienced by CAI patients, whereby insufficiencies in postural control limit functional performance, and increase the risk of reinjury, which can further increase the constraints and disability of the patient.[9]

Balance training has been used to improve postural control in CAI patients,[7] and has also been shown to decrease the risk of recurrent ankle sprains.[10] The use of balance training dates back to 1965 when Freeman et al.[11] found that (1) patients who reported recurrent episodes of their ankles giving way had diminished single limb balance and (2) using single limb coordination training significantly reduced the complaints of instability and eliminated the proprioceptive deficit in 11 out of 14 of the original patients. Since then, strong consistent evidence continues to support the use of balance training to improve various patient- (e.g. Foot and Ankle Ability Measure),[12] clinician- (e.g. Star Excursion Balance Test [SEBT]),[13] and laboratory-oriented outcome measures (e.g. time-to-boundary)[7,14] in patients with CAI. However, the literature has focused on whether or not the treatment group's mean improvement from baseline is greater than the control group's mean improvement rather than the proportion of patients who do and do not have favorable outcomes following clinical intervention (i.e. responders and non-responders). Along these lines, 25–50% of CAI patients had a meaningful improvement in balance after receiving 2-weeks of manual therapy treatments while the remaining patients did not.[15] Thus, assuming that all patients within a group will demonstrate a similar level of improvement (i.e. relying solely on group means) may mask a more typical bimodal response and impair clinical decision making.

Clinical prediction rules (CPRs) have the potential to provide clinicians with a practical, evidence-based tool to assist with the identification of patients that are more likely to have a meaningful improvement following a given intervention. CPRs have been developed for treating lower extremity musculoskeletal conditions such as patellofemoral pain with orthotics,[16] acute ankle sprains with manipulative therapy,[17] and CAI with sensory-targeted ankle rehabilitation strategies (STARS).[15] Considering the consistent recommendations to use balance training in the treatment of lateral ankle sprains and CAI, it is surprising that probability estimates of treatment success following balance training are unknown and that no CPRs yet exist for this treatment.

Therefore the purpose of this study was to conduct a secondary response analysis on data acquired through previous intervention studies which included CAI patients in order to (1) quantify the effectiveness of balance training and (2) identify possible predictors of treatment success following a balance training program. More specifically, we chose the posteromedial reach direction of the SEBT as our primary outcome as it is the most representative of overall SEBT balance performance.[18] Multiple studies have also reported SEBT-PM improvements post balance training[11–13] and evidence suggests that decreased (i.e. worse) SEBT-PM reach scores may double the risk of injury in basketball players.[19] More specifically, we aimed to use CAI patients as an injury model and use patient characteristics (e.g. age, height, weight, etc), injury history (e.g. number of sprains, etc), and baseline assessments of patient- and clinician-oriented outcomes to identify key characteristics in CAI patients who would have the highest probability of meaningful improvements in dynamic balance after completing the 4-week progressive balance training program.

2. Methods

We conducted a secondary analysis of data from six previous investigations that all examined the effects of an identical balance training program on those with CAI (Table 1). One investigation was the original randomized controlled trial during the development of this balance training program.[12] Three investigations compared balance training against balance training combined with additional interventions[13,14,20]; therefore only data from the standard balance training groups were used for this investigation. Two of the included investigations are from marked theses and dissertations that utilized the program but are otherwise unpublished or in review.[21,22]

The CAI participants that were randomized to the balance training program were physically active young adults and were tested in research laboratories at three large public universities. Most

Table 2
Univariate comparisons between the successful and unsuccessful groups based on SEBT-PM[a] scores exceeding the minimal detectable change score of 8.15%.

Variable	Successful (n = 28, 38.4%)	Unsuccessful (n = 45, 61.6%)]	p Value
Sex: female, n (%)	14 (50%)	28 (62%)	0.317
Age (years)	21.07 ± 3.76	19.93 ± 2.41	0.119
Height (cm)	172.02 ± 11.06	170.64 ± 8.59	0.552
Mass (kg)	73.90 ± 21.22	72.43 ± 12.65	0.711
# of recurrent sprains	3.29 ± 2.87	3.71 ± 4.40	0.651
Self-reported function[b] (%)	83.27 ± 8.97	87.77 ± 7.47	0.023[g]
Self-reported function: sports[c] (%)	71.03 ± 15.20	73.21 ± 13.66	0.528
SEBT-A[d] (% leg length)	63.87 ± 9.60	75.29 ± 10.67	0.007[g]
SEBT-PM[a] (% leg length)	75.60 ± 10.61	87.16 ± 13.14	0.001[g]
SEBT-PL[e] (% leg length)	72.91 ± 17.98	80.40 ± 14.50	0.055[g]
SEBT-C[f] (% leg length)	72.30 ± 11.53	80.95 ± 11.23	0.002[g]

[a] Star Excursion Balance Test Posteromedial Reach.
[b] Measured by the Foot and Ankle Ability Measure or Foot and Ankle Disability Index.
[c] Measured by the FAAM-S or Foot and Ankle Disability Index Sport Scale.
[d] Star Excursion Balance Test Anterior Reach.
[e] Star Excursion Balance Test Posterolateral Reach.
[f] Star Excursion Balance Test Composite Score.
[g] Variables are significant between groups of successful and unsuccessful treatment responses $p < 0.10$ and retained in the regression model.

of these investigations were initiated prior to the International Ankle Consortium's published recommendations for CAI research inclusion criteria,[23–25] however the inclusion criteria for all of the included datasets are comparable to these recommendations. Specific inclusion and exclusion criteria for each study can be seen in Table 1. Participant characteristics can be seen in Table 2.

Each participant included in the analysis completed the 4-week progression-based balance training program developed by McKeon et al.[12] The program consisted of 12, 20-min sessions over a 4-week period that incorporated 5 exercises that progressed in difficulty independent of one another. Full descriptions of the exercises and progression criteria can be seen in Appendix A.

Each investigation collected patient demographics, ankle injury history, dynamic postural control, and patient-reported function at baseline. Patient characteristics common to all studies included demographics such as age, height, mass, and sex. Injury history information common to all studies included the total number of ankle sprains sustained by the individual. Patient-reported function was recorded using either the Foot and Ankle Ability Measure activities of daily living (FAAM) and sports (FAAM-S)[13,14] or Foot and Ankle Disability Index activities of daily living (FADI) and sports (FADI-S)[12] with lower percentages representing more perceived dysfunction during activities of daily living or sports. Dynamic postural control was assessed using the SEBT in all studies. All participants completed the SEBT on the training limb in three directions, anterior (SEBT-A), posteromedial (SEBT-PM), and posterolateral (SEBT-PL). Participants in each investigation were instructed to complete the test by reaching their non-stance limb as far as they could on a flexible tape measure without lifting or moving the stance foot from the center of the testing grid, removing their hands from their hips, or excessive hip rotation. The reach distance of each trial (cm) was normalized to leg length, defined as the distance from the ASIS to the ipsilateral medial malleolus, and the average of 3 trials was used for analysis.[26] The SEBT composite (SEBT-C) score was also calculated, modified from Plisky et al.,[19] where the normalized reach score for all three directions were summed, divided by 3, and multiplied by 100. The SEBT is known to have a learning effect, and it is recommended that participants perform practice trials in order to attribute changes in SEBT performance to the intervention.[19,26,27] Investigators in each of the 6 studies made an effort to accommodate this learning effect by performing between 3 and 4 practice trials in each direction prior to taking the 3-trial average of the test trials.

Participants were dichotomized as having successful or unsuccessful treatments based on the change in the SEBT-PM score from baseline to post-test. A successful treatment was defined as a change in SEBT-PM score that exceeded the minimal detectable change (MDC) for the SEBT-PM (8.15%).[26] The MDC, an estimate of a measure's responsiveness over time, is generated from a non-intervention group over time. Thus, determining treatment success relative to an MDC score is comparable to including a non-intervention arm. For example, McKeon et al.[12] utilized a non-intervention control group, and reported no balance differences from pre- to post-testing. Individual predictor variables were tested for univariate relationship with the reference criterion (e.g. MDC) using independent samples t-tests for continuous variables and χ^2 tests for categorical variables.[16,17] Variables with a significance level of $p < 0.10$ were retained as potential predictor variables.[17] This significance level was selected, as previously reported, to reduce the chance that potentially important predictor variables might be overlooked.[15] Potential predictor variables were then entered into a stepwise logistic regression model to determine the most accurate set of variables for prediction of treatment success.[16,17] Variables with a significance level $p > 0.10$ were removed from the equation to further minimize the risk of excluding variables that could help strengthen the model. Variables retained in the regression model served as the predictors in the CPR.

All potential predictor variables were also submitted to a receiver operator characteristic curve analyses.[16,17] Sensitivity, specificity, positive (+LR) and negative likelihood ratios (−LR), and odds ratios were then calculated for identified cut-off scores for each potential predictor variable. Similarly, diagnostic accuracy and probability of success was calculated for the various combinations of predictor variables. Cut-off scores were identified using Youden's index, or identifying the maximal value of the sum of sensitivity + specificity − 1.[28] This number represents the predictor variable's score with the best diagnostic accuracy,[28] allowing for a CPR to be developed from the cut-off scores with each variable included in the final model.[15] Post-test probability of treatment success was calculated using the +LR and assumed a pre-test probability equal to the proportion of patients who exceeded the SEBT-PM MDC prior to stratification (i.e. prior to being grouped based on potential predictor variables).

3. Results

After completing the balance training program, 28 of 73 patients (38.4%) were considered to have a successful treatment with a mean (±SD) SEBT-PM improvement of 14.8 ± 4.8% relative to the unsuccessful group (45 of 73 patients [61.6%], 2.3 ± 4.3%). The univariate comparisons of the potential predictor variables between successful and unsuccessful groups sorted by treatment group can be seen in Table 2. Univariate variables that were retained after the step-wise regression for SEBT-PM success and combinations of predictor variables can be seen in Table 3. The variables in the regression analysis included both patient- (Self-reported function) and clinician-oriented (all SEBT directions and SEBT-C) outcomes. As illustrated in Table 3, the SEBT-PM is the individual predictor with the greatest post-test probability (63.5%). In other words, individuals with pre-treatment SEBT-PM reach distances ≤85.2% had a 63.5% chance of a meaningful improvement in SEBT-PM scores. However, the most robust method to predict a meaningful improvement in dynamic postural control following balance training was a SEBT-PM reach distance ≤85.2% combined with a self-reported function score ≤92.5% as this model resulted in a

Table 3
Sensitivity, specificity, positive likelihood ratio, post-test probability, and odds ratios for individual predictor variables and predictor variable combinations, when applicable.

	Sensitivity (95% CI)	Specificity (95% CI)	Positive likelihood ratio (95% CI)	Posttest probability	Odds ratio (95% CI)
Individual predictor variables (pre-test probability = 38.4%)					
Self-reported function ≤92.5%[a]	92% (77–98%)	33% (21–48%)	1.39 (1.11–1.75)	46.1%	6.5 (1.36–31.12)
Anterior SEBT reach distance ≤78.6%	89% (73–96%)	42% (29–57%)	1.55 (1.17–2.05)	48.6%	6.09 (1.6–23.16)
Posteriomedial SEBT reach distance ≤85.2%[a]	82% (64–92%)	71% (57–82%)	2.84 (1.74–4.64)	63.5%	11.32 (3.54, 36.2)
Posteriolateral SEBT reach distance ≤78.9%	64% (46–79%)	69% (54–80%)	2.07 (1.24–3.46)	55.9%	3.99 (1.47, 10.81)
Composite SEBT reach distance ≤81.2%	79% (61–90%)	58% (43–71%)	1.86 (1.26–2.76)	53.3%	5.02 (1.71, 14.76)
Predictor variable combinations (pre-test probability = 38.4%)					
Both self-reported function ≤92.5% and posteromedial SEBT reach distance ≤85.2%	79% (61–90%)	80% (66–89%)	3.93 (2.12–7.27)	70.7%	14.67 (4.59, 46.84)

CI: confidence interval, SEBT: Star Excursion Balance Test.
[a] Retained in regression model.

70.7% posttest probability of success. This model also had a positive LR of 3.93, which may indicate a meaningful shift in the posttest odds.

4. Discussion

In this secondary analysis of data from six investigations using identical balance training programs, we identified individual and a combination of variables that could predict which CAI patients are more likely to have a meaningful improvement in dynamic balance following the 4-week intervention. Specifically, we identified that self-reported function during activities of daily living and the SEBT-PM can be used to predict balance improvements following 4-weeks of this particular balance training program.

It is generally accepted that balance improves after balance training in both injured and uninjured populations. This is based on comparing pre- and post-intervention differences in group means. Using this approach, five of the six included studies reported significant improvement in SEBT-PM scores after completing 4-weeks of balance training (except Anguish and Sandrey[20]; Table 1). When combined ($n = 73$), significant pre- to post-intervention mean improvements in all 3 SEBT directions are identified (Hedges' g effect sizes: SEBT-A = 0.65, SEBT-PM = 0.95, SEBT-PL = 1.16). However, our response analysis contradicts these findings as only 38% of participants had a meaningful improvement in dynamic balance (i.e. an SEBT-PM change that exceeded the MDC of 8.15%). Clearly, patients with a drastic improvement in balance scores are skewing the post-intervention means and thus allow for statistical improvements in group means to be noted. Although between-group means and effect sizes are useful for determining treatment efficacy, they may over simplify clinical decision making and downplay the importance of personalized treatment plans based on specific impairments.

The practice of reporting both group means and the percentage of patients responding to a given treatment could certainly improve clinican decision making for patients with musculoskeletal injuries. The individual predictors noted in the current investigation have good to very good diagnostic utility. For instance, using the self-reported function ADL cutoff score of 92.5% there was only an 8% false negative rate (1 – Sensitivity), but there was a 67% false positive rate (1 – Specificity). The higher sensitivity of this measure (92%) suggests that the strength of the self-reported function questionnaire in this model is in identifying patients that are likely to not improve their balance after balance training. A similar diagnostic relationship is seen with the Ottawa ankle rules, which has a very high sensitivity and allows providers to rule out ankle and foot fractures with a negative test result. However, the test has a poor specificity, meaning that positive tests do not guarantee a fracture is present.[29] In addition, our results suggest that the SEBT-PM is the strongest individual predictor of treatment success. The false negative rate of this measure is moderate, at 18%, however it had the lowest false positive rate out of any of the predictor variables (29%). When participants met this criterion there was a 23% increase in the probability of a successful treatment. Cumulatively, our results support the use of a multi-dimensional evaluation of patient function prior to treatment prescription to improve the likelihood of a successful treatment, as our most profound results are apparent when a patient meets both the self-reported function and SEBT-PM criteria.

The current data would suggest that only 1 in 3 CAI patients would positively respond to a balance training program. Yet our data also indicates that a quick pre-treatment screening may improve this success rate. For example if a clinician had a group of 10 patients with a self-reported function score ≤92.5% and a normalized SEBT-PM reach distance ≤85.2%, ~7 of these patients would have a meaningful improvement in dynamic balance after completing this balance training program. This means that a 15-min screening can increase the probability of treatment success by 30%. Importantly, this combination of predictors had a relatively low false negative (21%) and false positive (20%) rate, suggesting it has an acceptable sensitivity and specificity for identifying CAI patients who respond to balance training. This increase in the probability of a successful treatment for a select group of CAI patients highlights the benefit of an impairment-based model (i.e. treating identified assessments rather than relying on a standard set of treatments for a given pathology).[30]

The results of our response analysis and CPR are consistent with those of Wikstrom and McKeon.[15] Their results demonstrated that ankle joint mobilizations, plantar massage, and calf-stretching resulted in meaningful balance improvements in 25–50% of their sample of CAI patients depending on the intervention in question. However, the presence of specific patient characteristics resulted in post-test probabilities ranging from 75 and 99% among these three common interventions. Similar to the results of the present analysis, Wikstrom and McKeon[15] reported a high likelihood of improving balance (99%) when a patient had a combination of poor balance and lower scores of self-reported function. This measure of self-reported function was identified as a significant predictor of treatment success for all 3 treatments analyzed.[15] The ability of patient-reported function to identify patients more likely to positively respond to both manual therapies and balance training also highlights the necessity of incorporating patient-reported outcomes into clinical practice.

It is important to note that multiple MDC values exist for the SEBT testing protocol. We chose the more conservative (i.e. higher) value[26] but a lower value (3.36% for SEBT-PM) generated from CAI patients[31] does exist. Using this value, our pre-test probability would be ~65%. Regardless of the MDC value (i.e. measurement error) used, it has not been determined whether or not exceeding the MDC is a *clinically significant* change in a CAI patient's balance. Unfortunately, this is not a new problem as Hertel et al.[18] called for the establishment of a minimal clinically important difference (MCID) for the SEBT in CAI patients over a decade ago. Until an MCID has been established for common clinician-oriented outcomes, we suggest using the standard error of measurement and MDC to complement the traditional between-group effects by reporting the percentage of patients that respond favorably to treatments.

This investigation is not without limitations. While the FADI and FADI Sport are the precursors to the FAAM and FAAM-S, and thus contain nearly identical content and are both reported as a percentage,[32,33] the use of different self-reported function measures must be noted. Further, the best individual predictor of treatment success was the baseline SEBT-PM, which was our criterion for treatment success. Although SEBT-PM reach distance has been shown to be related to overall performance on the SEBT[18] it is possible that since this variable is not independent of our criteria for a successful/non-successful treatment, it could have introduced bias into our analysis. It has been shown that SEBT-A reach performance is related to increased risk of lateral ankle sprain.[19] Furthermore, anterior reach distance during the SEBT has been shown to be related to dorsiflexion range of motion (DFROM).[34] Due to differences among the included investigations, we were unable to control for the influence of DFROM on reach performance in this direction. We could also only use a small number of possible independent variables to serve as potential predictors due to a limited number of consistent variables among the included investigations. While confident in the results, future research should focus on a wider range of measures capable of capturing the full spectrum of impairments present in patients with CAI. Lastly, our investigation is preliminary in nature and has not been validated in a large independent population of CAI patients or other populations (e.g. uninjured controls, ACL-R). Our results indicated that individuals with worse balance at baseline had the greatest improvements, likely due to the fact there was greater room for improving balance. This observation is probably not unique to patients with CAI, and would likely be observed in uninjured individuals as well as patients with other musculoskeletal injuries. Therefore further research should aim to validate the findings of CPRs using treatment outcomes in CAI patients and determine if similar response rates to balance training are present in other pathologic groups (e.g. ACL-R) or uninjured controls who would complete balance training programs as part of an injury prevention program.

5. Conclusion

Balance training has been shown to improve dynamic balance and self-reported function at the group level. However, when examining patient responses at the individual level, a bimodal response pattern emerged that affords clinicians the opportunity to identify patients who will most likely benefit from balance training in isolation. Our response analysis showed that both individual and a combination of patient- and clinician-oriented outcomes can increase the probability that a CAI patient may have a meaningful improvement in dynamic balance. In particular, patients who had a self-reported function score ≤92.5% and a SEBT-PM reach distance ≤85.2% were most likely to have a meaningful improvement in dynamic balance. Because of the clinical implications that a bimodal response has, we recommend that future interventional studies report a response analyses as a clinically-applicable analysis to augment traditional group comparisons.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.11.001.

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