The Effects of Gender and Fatigue on Dynamic Postural Control

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Context: Deficits in static postural control related to fatigue have been investigated previously, but there is little evidence to link fatigue to performance measures of dynamic postural control. Objective: To investigate the effects of fatigue and gender on performance measures of the Star Excursion Balance Test (SEBT). Design: Mixed-model design. Setting: Research laboratory. Participants: 16 healthy young adults. Intervention: Subjects performed the SEBT before and after 4 different fatiguing conditions. Main Outcome Measures: The normalized reach distances and sagittal-plane kinematics of the knee and hip were recorded. Results: Fatigue produced deficits in normalized reach distances and decreased knee flexion in all 3 reaching directions. Overall, women were able to reach farther than men while simultaneously demonstrating a greater amount of knee flexion. Conclusions: Gender differences were observed during performance of the SEBT, with women demonstrating greater reach distances and knee flexion, and fatigue amplified these differences.

Keywords: kinematics, Star Excursion Balance Test, balance

Fatigue is believed to increase muscle-spindle discharge, subsequently altering afferent information into the central nervous system and influencing joint awareness.1,2 Afferent information is a critical portion of the feedback loops that help create and maintain postural control. Previous studies have examined the negative effect fatigue has on measures of static postural control.3–11 However, there has been little investigation of the influence of fatigue on dynamic measures of postural control.12 Dynamic postural-control tasks require a greater degree of coordinated movement patterns using contributions from multiple joints,13 but it has not been established whether fatigue alters these tasks or the contributing joint patterns negatively.

Dynamic postural control can be assessed as the center of mass is controlled while one’s base of support is moving.13 In addition, as we examined in this study, dynamic postural control during performance of a voluntary task might involve completing a movement that translates the body’s center of gravity without com-
promising its base of support. There have been numerous tests developed to assess dynamic postural control in the geriatric population but very few tests that assess the dynamic balance capabilities of the athletic population. The Star Excursion Balance Test (SEBT) is one such test. It assesses maximum reach with 1 leg while maintaining a base of support with the other leg. The reliability and clinical applicability of the SEBT have been established. A previous study demonstrated that males are able to perform this task better, demonstrating larger reach distances than females. However, when the reach distances were normalized to the leg length of the stance limb, no significant gender differences were observed.

One technique for examining biomechanical contributions to a task is the use of kinematics to quantify movement patterns. Previous investigations have reported gender differences in knee-flexion angle and quadriceps activation during functional tasks. Although there have been limited comparisons of gender during performance of the SEBT, we could find no investigations reported in the literature involving SEBT performance that examined kinematic pattern differences in hip and knee flexion between males and females. In addition, there are few data that show the effects of neuromuscular fatigue on joint angle during the performance of this dynamic postural task.

There are neuromuscular and biomechanical differences between genders at the knee during functional tasks such as landing and cutting, with males demonstrating a larger amount of knee flexion than females. Although this gender difference in knee flexion is established in other selected tasks, it is not known whether there are similar differences throughout the lower extremity during a dynamic postural-control task such as the SEBT and how muscle fatigue could produce differences in neuromuscular control during the reaching task between males and females.

Therefore, the purpose of this study was to examine the effects of gender and fatigue of the sagittal-plane movers in the lower extremity on kinematic measures and dynamic postural control as measured with reach distance during performance of the SEBT. By systematically fatiguing sagittal-plane movers of the ankle, knee, and hip, differences in reaching strategies between male and female subjects were examined before and after fatigue. We hypothesized that (1) increased reach distance during the SEBT would occur simultaneously with increased knee flexion of the stance limb before and after fatigue, (2) reach distance and knee flexion would decrease after the fatiguing condition, (3) men would demonstrate greater reach distance and knee flexion than women before and after fatigue, and (4) the introduction of fatigue would amplify the gender differences described in hypothesis 3.

Methods

Participants

Sixteen physically active subjects (8 men: age 22.5 ± 2.45 years, height 1.81 ± 0.11 m, weight 81.59 ± 19.76 kg; 8 women: age 22.5 ± 2.56 years, height 1.67 ± 0.06 m, weight 60.61 ± 8.22 kg) volunteered for the study. All subjects participated in sustained physical activity at least 3 times per week for 30 minutes. They
signed a university-approved informed-consent form. All subjects had no history of injury to the lower extremity or vestibular disorders and had been free from mild head injury for the previous 6 months. Subjects were right-limb dominant, with limb dominance defined as the limb with which they preferred to kick a ball.

Procedures

Subjects reported to the laboratory for 5 testing sessions at least 1 week apart, during which they performed the SEBT before and after a fatiguing condition or a control, no-fatigue condition. The 5 testing conditions were isokinetic ankle fatigue, isokinetic knee fatigue, isokinetic hip fatigue, a lunging task, and control (no fatigue). The order of the 5 testing sessions was counterbalanced. Reach distance during the SEBT was measured while sagittal-plane kinematics of the stance leg were recorded. During each session, subjects completed the protocol using both the right and left legs; the order of stance leg was also counterbalanced. After completing the test with one leg, subjects sat quietly for 30 minutes before beginning the same protocol for the opposite leg.

During the initial session, leg length was measured with the subject lying supine on a plinth with a standard tape measure from the anterior superior iliac to the distal end of the medial malleolus. This measurement was used to calculate the dependent variable for normalized reach distance.

Instrumentation

An isokinetic dynamometer (Biodex, Inc, Shirley, NY) was used to induce fatigue in the sagittal-plane movers of the hip, knee, and ankle. A metronome was used to provide the rhythm of movement for performance of lunges. Subjects wore an adjustable weight vest (All Pro Exercise Products, Inc, Longboat, FL) carrying 10% of their body weight while performing the lunging task. Kinematic data of ankle-, knee-, and hip-joint positions were collected using a digital video camera (Panasonic Digital Palmcorder, Panasonic Electronics, Denver, CO) sampled at 30 frames per second. Joint angles in the sagittal plane were calculated using the SMART video-analysis system (ECI-Software, Inc, Boston, MA).

Star Excursion Balance Test

The Star Excursion Balance Test (SEBT) was performed with the subjects standing in the middle of a grid formed by 8 lines on the floor made with athletic tape extending out at 45° from each other17 (Figure 1). The SEBT consists of 8 reaching directions corresponding to the grid lines. Because of the constraints related to the timing of postfatigue measures and the fact that we were mainly concerned with sagittal-plane kinematics of the stance leg, only 3 of the 8 reaching directions—anterior (Figure 1[a]), medial (Figure 1[b]), and posterior (Figure 1[c])—of the SEBT were performed during the prefatigue and postfatigue conditions. During pilot work, these 3 reaching directions required the greatest amount of motion in the sagittal plane of movement compared with the other 5 directions.
Subjects were instructed to reach with their leg as far as possible along the line, make a light touch on the line, and return the reaching leg back to the center while maintaining a single-leg stance with the other leg in the center of the grid (Figure 1). They were instructed to make a light touch on the ground with the most distal part of the reaching foot and return to a double-leg stance. They were instructed to keep their hands on their hips and the heel of the stance leg on the ground at all times.

Figure 1 — Reaching in the (a) anterior, (b) medial, and (c) posterior directions of the Star Excursion Balance Test.
Reach distances were recorded by placing a mark on a measuring tape secured to the floor corresponding to the touchdown points of each subject. The investigator recorded the reaching distance as the distance from the center of the grid to the point of maximum excursion of the reaching leg. A trial was discarded and repeated if the investigator thought the subject used the reaching leg for a substantial amount of support at any time, removed his or her foot from the center of the grid, or was unable to maintain balance on the support leg throughout the trial.

Subjects participated in 5 separate testing sessions and on each testing day performed the reaching trials in each of the 3 selected directions of the SEBT before and after the designated condition. For each of the 4 testing sessions in which fatigue was induced, the designated fatigue protocol was completed between the pretrial and posttrial. On the control, nonfatiguing, day, subjects were allowed 5 minutes of quiet sitting between the pretest and posttest trials. At the beginning of each testing session, they were allowed to practice reaching in the 3 directions 6 times to minimize any learning effect. Subjects were afforded 5 minutes of rest between the practice trials and the pretest trials. The pretest trials consisted of 3 consecutive reaches in each of the anterior, medial, and posterior directions, with the directions randomized. After the 4 fatigue-condition sessions, posttesting commenced within 15 seconds of when the designated level of fatigue was achieved. The order of reach direction for the posttesting trials followed the same randomized order as the pretest for each testing session.

**Kinematic Analysis**

A digital video camera was positioned on a tripod 8 m from the center of the SEBT grid. Markers were placed on the acromion of the scapula, greater trochanter of the femur, lateral knee-joint line, and lateral malleolus. Subjects performed the test with the lateral side of the stance leg facing the camera. The single-camera setup allowed quantification of the amount of sagittal-plane motion in degrees at the knee and hip for all 3 reaching directions without subjects having to reposition their stance leg for each reaching direction.

Raw data were processed with Video Wave III video-processing software (MGI Software Corp, Ontario, Canada). The SMART system calculated kinematic data for hip flexion and extension and knee flexion and extension at the maximum reach distance, designated as touchdown of the reaching leg.

**Fatigue**

Three of the fatiguing conditions were performed on the isokinetic dynamometer, set for concentric–concentric function. Sagittal-plane movement patterns at the ankle (plantar flexion and dorsiflexion), knee (flexion and extension), and hip (flexion and extension) were used. Patient positioning followed guidelines set forth by the manufacturer.

Subjects performed 5 continuous maximum trials at 60°/s for the designated movement pattern to determine peak torque. After a 2-minute rest, they repeated the movement pattern at 60°/s continuously until force production dropped below 50% of the peak torque in both directions of motion being tested.

The fourth fatiguing condition consisted of performing a lunging task a maximum number of times. Subjects lunged forward with the leg that was to be their stance leg for the SEBT performance. Pieces of tape on the floor served as the
point of origin and the target reaching distance, equal to their individual leg length. Lunges were performed at the rate of 1 lunge every 2 seconds. A lunge cycle was defined as having the subject reach toward the target, achieve approximately 90° of hip and knee flexion in the lunging leg while maintaining an upright trunk, and return the reaching leg back to the point of origin.

Subjects were given ample practice time to ensure proper execution of the lunging task. They were given 2 minutes to rest between practice trials and test trials. Fatigue was induced by having them perform the task a maximum number of times until they could not complete it with proper form or were unable to meet the required rhythm for 2 repetitions in a row. Throughout the task, subjects received verbal cues to ensure proper technique and verbal encouragement to continue the task until fatigued.

The fifth testing session was used to establish baseline data and involved the control condition. During this session, no fatiguing task was implemented. Instead, the subjects sat quietly for 5 minutes between the pretest and posttest performances of the SEBT.

**Statistical Analysis**

The means of reach distance and maximum joint-flexion angles from the 3 trials of each performance of the SEBT were calculated and used for statistical analysis. Reach distances were divided by leg length and multiplied by 100 to calculate a dependent variable that represents reach distance as a percentage of leg length (MAXD). Because of the inherent differences in movement patterns between the 3 reaching directions, there were no direct comparisons made, and each was analyzed separately. For each reaching direction, 3 separate 5 × 2 × 2 × 2 ANOVAs were performed for normalized reach distance, knee-flexion angle, and hip-flexion angle with within factors of condition (control, ankle, knee, hip, and lunge fatigue), side (left and right), and time (prefatigue and postfatigue) and a between factor of gender (male and female). Tukey’s post hoc testing was performed to identify specific differences in the presence of a significant interaction. The level of significance was set a priori at .05 for all analyses. All statistical analyses were performed using SPSS 10.0 (SPSS, Inc, Chicago, IL).

**Results**

For the 5 pretest sessions, ICC values were calculated for the dependent variables in each reaching direction. ICC values for MAXD ranged from .941 to .951, for knee flexion from .876 to .935, and for hip flexion from .927 to .964. This indicates high reliability of the pretest measures across the 5 testing sessions for all 3 reaching directions.

For all reported statistically significant interactions, there were also significant main effects. In the presence of a significant interaction, the interaction is more meaningful and attention is given to the interaction rather than the main effect. Therefore, because of the volume of information that would have been devoted to present all the significant main effects in the Results section, we have only provided the results of the statistically significant interaction effect and appropriate post hoc information, or statistically significant main-effect information if there was no significant interaction effect.
The factor of side was included in our research design, and we did test the right and left sides. We do not mention this factor in our results because in no instance did it contribute as a significant independent variable. Because we did not report nonsignificant findings, side is not mentioned. We feel that the volume of the results precludes us from reporting all the nonsignificant findings.

**Anterior Direction**

**MAXD.** For the anterior reaching direction, fatigue created a decrease in MAXD for both genders compared with the control day; however, among the men, the knee fatigue condition produced a significantly greater decline in MAXD (–.043) than in the other conditions (gender-by-condition-by-time interaction: $F_{4,56} = 3.52, P = .012$; Figure 2).

**Kinematics.** Kinematically, a significant gender-by-condition interaction ($F_{4,56} = 2.54, P = .05$) demonstrated that women used more knee flexion than men during 3 of the fatigue conditions (ankle, knee, and lunge), with the largest disparity between genders for knee flexion for the lunge fatigue condition (7.96°; Figure 3). Similarly, women used more hip flexion (29.10° ± 4.24°) than men (11.43° ± 4.24°) during the reaching task (Gender: $F_{1,14} = 8.68, P = .01$).

**Medial Direction**

**MAXD.** For the medial reaching direction, all 4 fatigue conditions created pre–post decreases in MAXD (condition-by-time interaction: $F_{4,56} = 7.04, P < .001$) and knee flexion (condition-by-time: $F_{4,56} = 4.69, P = .002$) compared with the control day (Figure 4). However, women reached significantly farther after fatigue (0.882 ± 0.021) than men (0.847 ± 0.021; gender-by-time: $F_{1,14} = 5.81, P = .03$; Figure 5[a]).

**Kinematics.** Before fatigue, the women used a larger amount of knee flexion (72.36° ± 2.58°) than the men (67.72° ± 2.59°; gender-by-time: $F_{1,14} = 7.16, P = .018$; Figure 5[b]). In addition, the women experienced a smaller pretest-to-posttest decline in knee flexion (–1.54°) than the men (–4.16°; Figure 5[b]).

**Posterior Direction**

**MAXD.** For the posterior reaching direction, women produced larger MAXD values than men at the prefatigue and postfatigue sessions, and women’s MAXD was less affected by fatigue than the men’s (gender-by-time: $F_{1,14} = 6.67, P = .022$; Figure 6[a]). Fatigue at the ankle, knee, and lunge exercises created significant pre–post decreases in MAXD (condition-by-time: $F_{4,56} = 5.82, P = .001$; Figure 7[a]).

**Kinematics.** Women used a significantly larger degree of knee flexion after fatigue (60.36° ± 3.03°) than the men (54.56° ± 3.03°; gender-by-time: $F_{1,14} = 8.375, P = .012$; Figure 6[b]). In addition, ankle (–2.93°) and lunge fatigue (–3.95°) created significant decreases in knee flexion after fatigue (condition by time: $F_{4,56} = 6.68, P < .001$; Figure 7[b]).
The results of this study show that fatigue in the lower extremity adversely affects dynamic postural control as assessed with the SEBT. In addition, gender influenced performance of the different reaching directions of the SEBT. When examining the relationships between joint-angle positions and MAXD, the influences on performance center most significantly on the knee, with noticeable contribution from the hip. When fatigue is introduced the gender differences in MAXD and lower extremity kinematics become amplified.

Figure 2 — Gender × Condition × Time interactions for reach distance as a percentage of leg length (MAXD) in the anterior direction for (a) men and (b) women. *P < .05. With the men, the lunge fatigue condition created a significant decline in MAXD after fatigue.

Comments

The results of this study show that fatigue in the lower extremity adversely affects dynamic postural control as assessed with the SEBT. In addition, gender influenced performance of the different reaching directions of the SEBT. When examining the relationships between joint-angle positions and MAXD, the influences on performance center most significantly on the knee, with noticeable contribution from the hip. When fatigue is introduced the gender differences in MAXD and lower extremity kinematics become amplified.
Effects of Gender

Although previous data have shown few differences across gender for normalized reach distances during performance of the SEBT, there has been no investigation into gender differences in reaching strategies that might be used during these tasks. It appears that the ideal reaching pattern to produce the maximum reach in the anterior direction involves as much knee and hip flexion as possible and that any influence of gender on MAXD is influenced by sagittal-plane positioning of the knee and hip. Electromyographic activity of the vastus medialis oblique and vastus lateralis in the stance limb has been shown to be greater in the anterior direction than during any of the other reaching directions of the SEBT. Our results indicated that women achieved a greater amount of knee and hip flexion than men. Perhaps the women are able to recruit the medialis oblique and vastus lateralis more efficiently, allowing for better control of the knee in the sagittal plane during this task.

Performance in the medial and posterior reaching direction also appears to be significantly influenced by the position of the knee in the sagittal plane. Women were able to produce significantly larger MAXD values while simultaneously producing greater knee-flexion angles in this reaching direction. Although these analyses were examined individually, it might be concluded that women perform better at this task partially because of their ability to create a greater degree of knee flexion.

Previous investigations into kinematic variations during functional activities between genders have found noticeable decreases in knee flexion in women. Lephart et al observed a decreased knee-flexion landing angle during hopping tasks with decreased peak torque to body mass of the hamstrings and quadriceps.
Huston et al\textsuperscript{25} reported a significantly smaller degree of knee flexion during a drop-landing task in females. During the stance phase of 3 running and cutting activities, Malinzak et al\textsuperscript{24} described decreased knee-flexion angles in concert with increased quadriceps and decreased hamstring activation.

\textbf{Figure 4} — Condition $\times$ Time interactions for (a) reach distance as a percentage of leg length (MAXD) and (b) knee flexion in the medial reach direction. *$P < .05$. For both dependent variables, the lunge, knee, ankle, and hip fatigue conditions created a significant decline after fatigue compared with the no-fatigue condition.
Although the 3 reaching directions involve tasks requiring unique movement patterns and are considered inherently different, men demonstrated smaller knee-flexion angles in the 3 reaching directions than women. Perhaps the issue that is dictating the gender pattern in the SEBT that is inconsistent with other functional measurements is the ability of subjects to perform the SEBT at a self-selected pace. Future investigations should investigate sensorimotor integration across

*Figure 5* — Gender × Time interactions for (a) reach distance as a percentage of leg length (MAXD) and (b) knee flexion in the medial reaching direction. *P < .05, time difference. +P < .05, group difference.
Figure 6 — Gender × Time interaction for (a) reach distance as a percentage of leg length (MAXD) and (b) knee flexion in the posterior reaching direction. *P < .05, time difference. +P < .05, group difference.
Figure 7 — Condition × Time interaction for (a) reach distance as a percentage of leg length (MAXD) and (b) knee flexion in the posterior reaching direction. *$P < .05$. For MAXD, the ankle, knee, and lunge fatigue conditions created a significant decline after fatigue. For knee flexion, the ankle and lunge fatigue conditions created a significant decline after fatigue.
various functional measures to determine whether the speed of the task and associated interaction with the environment dictates performance between genders.

Constraints-behavior theory, influenced by the interaction of task, organismic, and environmental constraints, might be useful in examining these differences.\textsuperscript{29} In this experiment, task and environmental constraints were the same for men and women, suggesting that the observed differences must be organismic. Organismic constraints can be categorized as structural and functional. From a structural perspective, women might have gained an advantage by maintaining their center of mass lower because of wider hips.\textsuperscript{30,31}

From a functional perspective, Zeller et al\textsuperscript{30} found that during single-leg squats, females demonstrated greater ankle dorsiflexion and pronation, hip abduction, flexion, and external rotation and less trunk lateral flexion than males. They attribute the differences to females’ starting in and maintaining a more valgus position of the knee, which would create a wider pelvic base and lower the center of mass, creating better stability, potentially influencing the joint position throughout the extremity.

Van Wegen et al\textsuperscript{31} have demonstrated differences in static postural control between elderly and younger populations as measured through time-to-boundary values. This method of assessing postural control, which examines the temporal safety margins of postural sway, has not been compared between genders or during the SEBT; however, it might be that the decisions to employ knee flexion to complete the task reflect one’s ability to efficiently challenge the temporal safety margins of the boundaries of the base of support. Effective management of the interaction of the demands of the task and the environmental constraints is perhaps manifested as increased knee flexion. Future studies should quantify time-to-boundary values to determine the degree to which these margins might influence a dynamic postural-control task.

**Effects of Fatigue**

For men and women, fatigue had a negative influence on knee flexion that adversely affects MAXD. The ankle and lunge fatigue tasks influenced knee-flexion-angle changes while simultaneously reducing MAXD. Although the induced fatigue conditions were designed to influence muscle groups about specific joints, those influences do not seem to be constrained to the targeted joints, as observed from the kinematic changes in the knee and hip.

In our study, MAXD and knee flexion experienced simultaneous deficits with the knee-fatigue protocol. Electromyographic activity of the vastus medialis oblique and vastus lateralis in the stance limb has been shown to be greater in the anterior direction than during any of the other reaching directions of the SEBT.\textsuperscript{28} With fatigue, the vastus medialis oblique and vastus lateralis might have lost the ability to effectively contract to help maintain dynamic postural control during this task. We did not quantify this, but the potential alteration in muscle activation after fatigue could have influenced the knee and hip angles, subsequently contributing to a decrease in MAXD. In addition, the women appeared more resistant to changes in MAXD, knee flexion, and hip flexion after fatigue, again alluding to potential gender differences related to fatigue and motor-unit recruitment of the
quadriceps. Future studies should use EMG to further quantify these observed differences across genders related to fatigue.

It has been suggested that females are more resistant to fatigue at lower intensities. In all 3 reaching directions, women performed better, and the gender differences were amplified by fatigue, suggesting that the men were more adversely affected by fatigue. The human movement system seems to have a significant energy-minimization bias that, in certain tasks, must be overcome if performance is to be maximized. The SEBT creates a problem of conflicting goals of maintaining balance and maximizing reach distance. Having to perform the task under fatigued conditions might have shifted the influence toward energy minimization, evidenced by a reduction in reach distance. Although the SEBT is a challenging task, perhaps its metabolic demand is low enough that women are less resistant to altered performance in a state of fatigue and do not need to minimize their energy for the task, allowing them to still use selected movement strategies more efficiently than men.

**Limitations**

The kinematic analyses in our study only reported sagittal-plane movements. There are multiple combinations of multiplanar movement that might be occurring during all 3 reaching tasks that we were unable to quantify in this project. Rotation at the hips and trunk that was not quantified in this study might have influenced the performance of the task. Future investigations should involve more sophisticated means of kinematic analysis to help describe the contributions of motion outside the sagittal plane.

We chose to report our data related to the effects of fatigue on the selected task using a pre–post variable (time) and the examination of the 5 separate fatiguing tasks (condition). An alternative approach to these relationships would have been to present delta scores to represent the change in fatigue over time in place of the raw pretest and posttest scores. Although that approach could have provided a simpler design, we felt that it was important to retain the pretest comparisons so that the additional purpose of examining the influences of gender before fatigue could be achieved. In addition, there is evidence to suggest that the use of delta scores in an ANOVA model is associated with a weaker level of reliability than using raw scores. Also, the ICC values for our reach distance and kinematic dependent variables during the pretest assessments when comparing the 5 separate testing days ranged from .876 to .964, indicating that reliability of the pretest measures was strong, which we felt allowed us to use pre–post raw scores for comparison.

A few enforced task constraints might have influenced the subjects’ performance. The participants were required to keep their hands on their hips and their heels in contact with the floor. This might have altered their reaching strategy, but we felt that it was more important to standardize the instructions for performance in an attempt to minimize error because of excessive accessory motions at uncontrolled joints.

A limitation with any study using isokinetics is the concern related to subjects’ effort levels. It is difficult to control the individual level of effort that a
subject produces when asked to provide maximum effort and sustain that level during a fatiguing condition. In an effort to control this, the same investigator provided the same verbal cues and encouragement to all subjects throughout all the tasks.

**Conclusion**

In conclusion, gender and fatigue appear to influence dynamic postural control as measured with the SEBT. Women performed better on the task than men, and one of the explanations for this finding is the increased knee flexion exhibited by the women at the point of maximum reach distance. This biomechanical difference between men and women was amplified under fatiguing conditions to the lower extremity as reach distances and knee flexion decreased in both groups with fatigue, but the decline was larger among the men. Future investigation into the neuromuscular contributions to the biomechanical differences resulting from fatigue in the lower extremities between genders should continue to examine the relationship of the knee during performance and by what mechanism fatigue influences the level of neuromuscular control inherent to men and women. When selecting appropriate rehabilitation tasks, clinicians should be aware that this task might be more challenging for men than women, as evidenced by the greater normalized reaching distances of the women. In addition, the SEBT might be an appropriate rehabilitation task for patients with sagittal-plane knee-motion deficits because it relies on and challenges sagittal-plane knee movement. Finally, clinicians should be aware that fatigue can influence dynamic postural control and use this to their advantage when formulating rehabilitation for the lower extremity, while taking steps to minimize fatigue if optimal performance on the task is desired.

**References**


