Influence of Age on Neuromuscular Control During a Dynamic Weight-Bearing Task

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Neuromuscular control strategies might change with age and predispose the elderly to knee-joint injury. The purposes of this study were to determine whether long latency responses (LLRs), muscle-activation patterns, and movement accuracy differ between the young and elderly during a novel single-limb-squat (SLS) task. Ten young and 10 elderly participants performed a series of resistive SLSs (0°–30°) while matching a computer-generated sinusoidal target. The SLS device provided a 16% body-weight resistance to knee movement. Both young and elderly showed significant overshoot error when the knee was perturbed ($p < .05$). Accuracy of the tracking task was similar between the young and elderly ($p = .34$), but the elderly required more muscle activity than the younger participants ($p < .05$). The elderly group had larger LLRs than the younger group ($p < .05$). These results support the hypothesis that neuromuscular control of the knee changes with age and might contribute to injury.

Keywords: long latency responses, elderly, motor control

Neuromuscular control is believed to be fundamental to minimizing undue stresses and strains to tissues that stabilize the knee (Riemann & Lephart, 2002; Williams, Chmielewski, Rudolph, Buchanan, & Snyder-Mackler, 2001). Because of incorrect central nervous system (CNS) programming in preparation for a weight-bearing load, noncontact knee injuries are prevalent during weight-bearing tasks (Griffin et al., 2000). Functional activities, which include climbing stairs, stepping off curbs, standing from sitting, descending stairs, and squatting to pick an item up from the floor, are everyday tasks that, if programmed incorrectly via the CNS, might contribute to injury with age. Accordingly, understanding age-associated changes in the CNS during unexpected weight-bearing perturbations might assist in developing new methods to prevent knee injury with age.

A natural consequence of aging is a loss of muscle mass and strength (Deschenes, 2004; Nikolic, Bajek, Bobinac, Vranic, & Jerkovic, 2005). Thus,
everyday tasks that normally require low levels of motor-unit recruitment are associated with higher levels of CNS drive to generate the necessary muscle forces. Increased CNS drive might lead to excessive reflex responses when coupled with an unexpected perturbation of a freely moving limb segment (Matthews, 1986). Previous studies have suggested that the elderly have prolonged reflex latencies and enhanced amplitudes during perturbations induced during quiet stance (Kawashima et al., 2004; Nardone, Siliotto, Grasso, & Schieppati, 1995). To our knowledge, however, no previous report has quantified the long latency responses (LLRs) during a weight-bearing task with coactivation of lower extremity muscles in the elderly.

One common method of assessing the neuromuscular response to a perturbation is to examine the muscles’ LLRs that occur before the volitional reaction time (Etty Griffin, 2003; Hewett, Paterno, & Myer, 2002). LLRs of the quadriceps have central and noncentral contributions and occur 50–200 ms after the perturbation (Mrachacz-Kersting, Grey, & Sinkjaer, 2006). Muscle-spindle, visual-input, and vestibular sensory systems “tune” LLRs during perturbations (Horak, Nashner, & Diener, 1990; Lewis, Polych, & Byblow, 2004; Petersen, Christensen, Morita, Sinkjaer, & Nielsen, 1998). Thus, the LLR during a weight-bearing task might be context specific (Bonnard, de Graaf, & Pailhous, 2004; Burleigh & Horak, 1996; Horak, Diener, & Nashner, 1989). The resistive single-limb task, as developed for this study, enables us to assess task competency (accuracy) and perturb the limb during active muscle contractions during weight bearing. Because we provided visual feedback and adequate time, we expected both the young and the elderly to attain a similar level of accuracy with this tracking task. The accuracy of the tracking task provides a method to “normalize conditions” before the perturbation to minimize individuals’ developing a “stiffness” strategy common in studies using unexpected perturbation. We previously demonstrated that increased coactivation of the quadriceps and hamstrings during this task is associated with poor accuracy (Madhavan & Shields, 2007). Thus, employing a similar accuracy strategy would enable us to compare the triggered LLRs as they would be triggered in “real life” conditions. In addition, the single-limb weight-bearing task is also a standard exercise used during rehabilitation programs to teach improved neuromuscular control (Escamilla et al., 1998; Toutoungi, Lu, Leardini, Catani, & O’Connor, 2000; Wilk, Reinold, & Hooks, 2003).

The purposes of this study were to determine whether LLRs, muscle-activation patterns, and movement accuracy differ between the young and elderly during a weight-bearing task. We hypothesized that (a) the elderly would show elevated LLRs of the quadriceps during unexpected perturbations, (b) they would recruit a higher percentage of muscle to perform the weight-adjusted single-limb-squat (SLS) exercise, and (c) the elderly and young would achieve comparable levels of accuracy in performing this task.

Materials and Methods

Participants

Ten healthy right-handed young men (age 24.2 ± 1.6 years) and 10 healthy right-handed elderly men (age 67.4 ± 8.2 years) participated in this study (Table 1).
Participants were excluded if they had a history of neurological deficits, musculoskeletal disorders, degenerative joint diseases, cardiovascular diseases, previous knee injury or surgery, previous fractures of the lower extremity, patellar dislocations, or past or current knee pain during activity or rest or were unable to ascend a flight of at least 10 stairs. All participants were recreationally active but were not undergoing any regular physical training program during the time of the study. After a brief description of the experimental protocol, participants signed an informed-consent document approved by the University of Iowa’s human subjects review board. In addition to filling out a medical questionnaire, participants completed the Short Form Medical Outcome Questionnaire (SF 36) to evaluate their health-related quality of life and perceived functional status (Ware, 1993). Participants also performed the single-leg-stance balance test (standing on the dominant leg for a maximum of 30 s) with eyes open and closed to measure balance impairments (Balogun, Ajayi, & Alawale, 1997).

### Justification for Age Differences

The young and older groups differed significantly on the physical-function domain of the SF 36 questionnaire ($p < .001$), suggesting that the elderly group perceived limitations in performing physical activities because of their health (Table 1). A significant difference was also found between the two groups in the single-leg eyes-closed balance test on the right leg ($p < .001$). On average, the young could maintain their balance for 24.6 s, whereas the elderly were able to stand on one leg with eyes closed for just 8.64 s. These two tests suggest that although the elderly represented a healthy participant group, they still differ from the younger group in terms of perceived functional status and measurable neurological tests. We tested standing balance on the dominant leg, a different limb than that being tested in this study, to get an index of CNS differences between the groups. It is tempting to equate the single-limb-stance balance test to the SLS task implemented in this study. However, pilot data indicate that body sway (center of pressure) during single-limb stance with eyes closed is reduced nearly 80% when participants are attached to the weight-bearing tracking system designed for this study. This is an important consideration because the device is designed to study perturbations in weight bearing in participants who otherwise might have balance impairments.
The degrees of freedom when attached to this instrumentation are reduced because only sagittal-plane motion is permitted. Accordingly, the limited degrees of freedom permit the safe delivery of perturbations in weight bearing in an intact system (visual, vestibular, somatosensory integration) without an emphasis on maintaining balance.

**Experimental Task**

The main task was for the participants to perform an SLS exercise on the left (nondominant) leg. We chose the nondominant leg because we wanted the task to magnify changes that might occur with age. It is possible that the dominant leg maintains neural control with age longer than a limb that is nondominant. The participants used a custom mechanical device that enabled them to perform the task while following a sinusoidal target (0.4 Hz, $T = 2,500$ ms) projected on a computer screen in front of them. Resistance (16% body weight) to both the knee-flexion and -extension phase of movement required that the participants increase their central drive to complete the task.

**Instrumentation**

We custom designed an SLS testing device for the purposes of this study (Shields & Madhavan, 2005). This system includes a rack-and-pinion gear and associated braking device to resist knee flexion and extension (Figure 1). We measured linear displacement of the knee with a potentiometer attached to the shaft of the brake. The brake was under current control from a microcomputer-controlled digital-to-analog output. A touch support force system provides for monitoring fingertip forces during SLS tasks. For this study, no participant exceeded 2 N.

The correlation between knee-joint angle and horizontal linear displacement was high (.98) in a separate unpublished pilot study using video analysis of knee angle. For ease of experimentation, all trials in this study were completed without kinematic assessment via video recording and marking of bony landmarks. For this reason the data will be presented in terms of linear displacement (cm), recognizing that this displacement is closely associated with knee angle, as previously established.

We displayed the linear motion of the knee on a computer screen directly in front of the participants. Their goal was to follow a sinusoidal target also projected on the screen. The peak-to-peak amplitude of the target corresponded to 15 cm of linear horizontal displacement, which was approximately 30° of knee flexion.

We recorded muscle activity of the rectus femoris (RF), vastus medialis oblique (VM), vastus lateralis (VL), lateral hamstrings (LH), and medial hamstrings (MH) of the exercised limb using surface electromyography (EMG). We placed bipolar silver-silver chloride EMG electrodes (8 mm in diameter) according to the landmarks described by Cram, Kasman, and Holtz (1998). Before the start of the SLS exercise we obtained the EMG activity during maximum voluntary isometric contractions (MVIC) of each muscle and presented all EMG activity during the SLS as a percentage of MVIC. MVICs were performed with participants seated on the chair of a Kin-Com isokinetic dynamometer (Kin-Com 125E+, Chattex Corp., Chattanooga, TN) with the knee joint positioned in 30° of flexion. Participants performed three MVICs in extension followed by three in flexion.
The trial with the highest recorded peak EMG was used to normalize the activity of each muscle during the resisted SLS task. Although this method does not identically normalize each muscle based on its length during the dynamic single-limb test, it does provide a relative measure of muscle activation for normalization across muscles and participants.

**Experimental Protocol**

Before the start of the experimental protocol, participants performed a standardized warm-up protocol on an exercise bike for 5 min. All participants performed five sets of the SLS exercise to get familiar with the platform and task. Each set consisted of 10 repetitions of the SLS. Previous studies have shown that motor learning of this task (tracking the sine-wave pattern with knee displacement) is achieved within five sets of 10 repetitions (Madhavan & Shields, 2007). Learning during these trials allowed both young and elderly to achieve a similar level of competency (within 3 cm of the target). We excluded 3 elderly participants who did not reduce their tracking error to within 3 cm of the target after training. The participants performed the task with the left leg and were instructed to relax their right leg and let it hang freely during the entire set.
After the practice trials, participants performed the perturbation trials. These trials consisted of five sets of 10 repetitions. Two of the five sets were selected randomly to have perturbations delivered. Two perturbations were delivered randomly within each of the two sets (of 10 perturbations). A perturbation consisted of the release of brake resistance from 16% of body weight to 0% body weight. Each release lasted for 500 ms and started when the linear knee displacement crossed the 250-ms mark of the target during the knee-flexion phase. This was at approximately 25% of the knee-flexion phase of the squat. Thus, the release occurred under identical knee-displacement positions for all experiments. We instructed the participants to continue following the target pattern as accurately as possible even when they felt a change in resistance level. A minimum of 1 min rest, as necessary, occurred between each set. After every set, participants were asked to report their rating of perceived exertion (RPE) of their quadriceps on the Borg Scale (Borg, 1982). If they perceived any fatigue of the quadriceps, they took additional time to rest. The Borg Scale is found to be sensitive to perceived levels of exertion in isolated muscle (Hunter, Critchlow, & Enoka, 2004; Hunter, Lepers, MacGillis, & Enoka, 2003). Participants reported their RPE to be very light throughout the entire session, indicating that their perception was that they were not fatigued. This finding was confirmed by the EMG, which showed no significant change from the fifth to the tenth set. Some changes in EMG during the first five sets are attributed to changes in motor-control strategy with learning (Madhavan & Shields, 2007).

Data Analysis

EMG, displacement, and target trajectories were collected and analyzed using Datapac II software (RUN Technologies, CA). We sampled the EMG at 2,000 Hz and the displacement at 1,000 Hz. We determined task accuracy by calculating the absolute error (absolute value of tracking signal minus target signal) and averaging the error in 10% bins of the flexion and extension cycles. We defined the error during the perturbations as the difference between the greatest flexion displacements relative to the distal target of the sinusoid target for knee flexion. In the event of a perturbation, the overshoot should be extensive if the participant did not expect the perturbation. Repeatability data indicate that the perturbation induced similar effects regardless of whether it was the first or second perturbation delivered during any set of 10 flexion displacements.

We normalized all EMG data as a percentage of each participant’s MVIC in sitting with the knee at 30°. We averaged each muscle’s EMG activation during the flexion and extension cycles.

To compare muscle responses to the perturbations, we determined the peak LLR of each muscle by calculating the peak EMG value during 50–150 ms after the perturbation and subtracting the peak EMG of the unperturbed trials, corresponding to the 50- to 150-ms period when a perturbation could have occurred:

\[
\text{Peak LLR} = \text{peak EMG of perturbation trials} - \text{peak EMG of unperturbed trials}
\]

We also normalized the peak LLRs of the quadriceps muscles 50–150 ms after the perturbation according to the following formula:

\[
\text{Normalized peak LLR} = \frac{\text{peak LLR}}{\text{mean EMG of unperturbed trial}}
\]
The time of the peak EMG activity in the 50–150 ms after the perturbation was calculated and reported as the latency of the peak LLR.

**Statistical Analysis**

We used a split-plot repeated-measures ANOVA to analyze for significant differences between the young and elderly groups for all the dependent variables. We considered the flexion phase and extension phase of the muscles separately to highlight the effect of the perturbation. In the event of a significant interaction between age and perturbation condition, we performed a simple-effects analysis. The criterion for significance for each test was .05.

**Results**

**Effectiveness of Perturbation Trials**

The consistent direction of the error induced during a perturbation trial indicates that the participants did not anticipate the perturbation, as shown in a single participant in Figure 2(a) and (b). An overlay of the EMG for a perturbed and nonperturbed condition displays the magnitude of the LLR during the perturbation for a representative participant (Figure 2[c] and 2[d]). Note the rapid movement into knee-flexion displacement (when the brake was released) resulting in a significant error that overshot the target by ~4.5 cm as compared with the nonperturbation condition \((p < .05; \text{Figure } 3[a])\). There was no difference in error between the younger and older groups during the perturbation trials, indicating a similar degree of knee displacement \((p = .56)\).

**LLRs**

The elderly showed an average 47%, 25%, and 45% increase in the peak LLR for the VM, RF, and VL muscles, respectively \((p < .05)\), as compared with the younger group (Figure 3[b]). A significant inhibition (10–20% MVIC) of the hamstrings (MH and LH) in both groups was present during the enhanced quadriceps LLR, but this inhibition was not different between the young and the old. When we normalized the long latency reflex response to the background EMG activity of the nonperturbation trials, the elderly showed an average 50% and 40% increase in long latency reflex response for the VM and VL, respectively \((p < .05; \text{Figure } 4)\). Less inhibition of the LH was also present \((p < .05; \text{Figure } 4)\).

The time latency of the peak response was, on average, 120 ms for the quadriceps in the younger group. The elderly group showed a delay in the peak response to 133 ms as compared with the younger group \((p < .05; \text{Figure } 5)\).

**Muscle-Activation Patterns**

All three quadriceps muscles (VM, VL, and RF) showed greater EMG activity in the elderly group than in the younger group during the knee-extension phase of the SLS \((p < .05; \text{Table } 2)\). Overall, during the extension phase, the elderly showed 61%, 21%, and 22% greater EMG activity of the VM, RF, and VL, respectively, than the younger group (Table 2). There were no differences in quadriceps EMG
activity between the young and elderly for the flexion phase of the SLS ($p = .42$). However, the elderly participants showed approximately 42% and 29% greater EMG activity of the MH and LH, respectively, than the younger group during the flexion phase ($p < .05$). There was significantly increased activity of only the LH (42%) during the knee-extension phase in the older group ($p < .05$).
Figure 3 — (a) Errors of the perturbation and nonperturbation trials for the young and elderly participants. The y axis depicts error in centimeters. Error bars represent standard error. (b) Peak long latency responses (LLRs) of the vastus medialis (VM), rectus femoris (RF), vastus lateralis (VL), medial hamstrings (MH), and lateral hamstrings (LH). The y axis measures the difference of nonperturbation peak EMG activity from perturbation long latency peak EMG activity as a percent of maximum voluntary isometric contraction (MVIC).

Accuracy of Performance

The young and elderly groups showed similar trends in performance of the SLS task, with the peak errors being midway between knee flexion and extension (Figure 6). There was no overall difference in absolute error between the younger and older groups ($p = .34$).

Discussion

A primary challenge for the CNS is to coordinate muscle activity in an effort to promote joint stability during functional activities. Joint stability requires a complex
Aging is associated with a significant musculoskeletal loss, as well as a decline in the visual, vestibular, and somatosensory systems (Nikolic et al., 2005; Stelmach, Phillips, Difabio, & Teasdale, 1989). Decline in central processing and slowing of performance in speed tasks are other consequences of age that challenge the motor-control system (Lassau-Wray & Parker, 1993; Salthouse & Somberg, 1982). The various changes that occur with age might predispose the elderly to injury.

The goal of this study was to examine how young and elderly adults control the knee during a weight-bearing activity and to examine differences in their interaction between the neural control system and the musculoskeletal system.
Table 2  Average Muscle Synergistic Activity (Expressed as % of Maximum Voluntary Isometric Contraction) of the Young and Elderly Groups During Performance of the Single-Leg Squat, $M (SD)$

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Flexion</th>
<th>Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young</td>
<td>Elderly</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>23.1 (23.9)</td>
<td>27.9 (20.7)</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>18.4 (25.8)</td>
<td>10.5 (9.0)</td>
</tr>
<tr>
<td>Vastus lateralis</td>
<td>35.5 (20.1)</td>
<td>28.7 (17.2)</td>
</tr>
<tr>
<td>Medial hamstrings</td>
<td>15.8 (13.6)</td>
<td>26.2 (23.0)</td>
</tr>
<tr>
<td>Lateral hamstrings</td>
<td>71.3 (42.3)</td>
<td>99.4 (51.8)</td>
</tr>
</tbody>
</table>

Figure 6 — Absolute error for young and elderly participants during the learning sessions when no perturbation was given. Flexion and extension displacements are divided into 10% increments of each respective cycle. Data points represent the mean of all participants, and error bars are standard errors.
nonvolitional responses to unexpected perturbations. The results supported our hypotheses that the elderly would show greater LLRs to unexpected perturbations, that they would use greater muscle activation than the young to perform certain parts of the weight-adjusted exercise, and that the elderly and young would show similar levels of competency (accuracy) in performing the SLS exercise, given adequate time for learning and visual feedback.

Weight-bearing exercise has been shown to improve lower limb strength, balance, and mobility in older individuals who are healthy and those with impairments (Bean et al., 2002; Hauer et al., 2001). In the current study, we assessed neuromuscular control of the lower extremity by using a target-tracking task during a weight-bearing activity (SLS). The absolute error of both groups followed a similar pattern throughout the SLS. The highest error occurred while the participant was accelerating toward the midpoint of the flexion and extension movement. The lowest absolute error occurred at the beginning and end of the flexion and extension cycle.

Although both groups used similar muscle-activation patterns, the elderly activated their quadriceps muscles at a higher percentage of MVIC than young individuals during the extension phase of the SLS. In addition, and just as important, the elderly used their hamstrings at a higher percentage of MVIC during the flexion phase. Thus, the primary agonists for this novel SLS resistive task are the hamstrings during the flexion phase and the quadriceps during the extension phase, both of which were elevated in the elderly. Given the natural atrophy with age, it is not surprising that the elderly required a higher percentage of these muscles to perform the flexion and extension phases of the SLS task. It is interesting that the antagonists (quadriceps) during the flexion phase were not different between the young and elderly groups. The similarity in antagonist activity (quadriceps) between the young and the elderly provided a unique opportunity to contrast the LLRs with and without normalization of background EMG activity.

Reflex activation, including LLRs, elicited by perturbations of a moving or stationary limb segment or by support-surface perturbations has been examined to further understand neuromuscular control of the human body (Chmielewski, Hurd, & Snyder-Mackler, 2005; Horak et al., 1989; Shultz et al., 2000). The involvement of a transcortical component (Petersen et al., 1998) and the adaptability of these responses with training (Horak et al., 1989) have made the LLRs a focus of many rehabilitation programs. LLRs are mediated by the spindle group Ia afferents through a supraspinal pathway in response to rapid stretch of an active muscle (Chan, 1983). These triggered muscle responses occur within 50–200 ms of a perturbation and are influenced by the perturbation’s duration, velocity (Lewis, Perreault, & MacKinon, 2005), and amplitude (Nardone, Giordano, Corra, & Schieppati, 1990); type of task performed (Bawa & Sinkjaer, 1999); previous experience (Horak et al., 1989); environmental context (Burleigh & Horak, 1996); and age (Nardone et al., 1995). Numerous studies provide valuable information about the effect of aging on LLRs, but these perturbations are associated with a primary balance task and involve the displacement of the standing support surface during quiet stance, with low levels of agonist–antagonist coactivation. Moreover, when balance is disturbed in elderly, they often develop an “increased stiffness” strategy that is different from their everyday activation. Studies have noted an increased latency of leg-muscle responses to perturbations,
altered temporal sequence of muscle activation, and an increase in the amplitude of responses (Nardone et al., 1995; Stelmach & Worringham, 1985; Woollacott, Shumway-Cook, & Nashner, 1986), but prior perturbation (central set) is known to influence these responses. In the current study, we demonstrated that the quadriceps LLRs are over 40% greater in the elderly, even when adjusted for muscle EMG background activity. This increase is present on the first and all subsequent perturbations, confirming that the goal of accuracy prevents the adoption of a stiffness strategy and keeps the central set fixed even though the participants were fooled. We suggest, for the first time, that excessive LLRs under these types of conditions might lead to soft-tissue injury during everyday unexpected perturbations in the elderly.

As indicated previously, we believe the required accuracy was an important component of this study. A common strategy in whole-body-perturbation research is to stiffen the leg for all subsequent trials after the delivery of the first unexpected perturbation. However, stiffening the limb would compromise the performance accuracy during this task, as was apparent in 2 of the elderly participants who could not perform the task accurately after the first perturbation. The consistent overshoot error in both groups during the perturbations indicates that the unexpected release of the brake fooled the participants. The participants’ focus on accuracy simulated a condition that is more lifelike during the experimental protocol. Indeed, it is common in an experimental condition to set the CNS in a default mode that strives to maintain stiffness of a limb, especially after the first unexpected perturbation. However, the requirement of maintaining accuracy at the time of a perturbation provides new insights into how the CNS responds when the goal of accuracy is included in the context of the task. Our data suggest that the greater the concentration given to task accuracy, the easier it is for repeated random perturbations to “fool” the nervous system. We also believe, for these reasons, that this task translates into real-life situations. For example, we know that injury commonly occurs when one steps down (off a curb) and the CNS programs incorrectly for the impending distance to landing because one is preoccupied with another task. The extent to which the CNS can assume a “default” mode that is more accommodating to unexpected perturbations is the focus of many rehabilitation scientists. Training paradigms that optimize CNS control might someday be instrumental in preventing musculoskeletal injury in the young, as well as in an aging society.

Participants in both groups demonstrated significantly increased quadriceps and inhibitory hamstrings LLRs during the 50–150 ms after the perturbation, compared with the corresponding time of the nonperturbation trials. Similar to some previous studies, the amplitude of the LLR was enhanced in the elderly participants (Nardone et al., 1990; Steffen, Hacker, & Mollinger, 2002). There was no difference in the background EMG of the VM and VL during flexion between the young and elderly groups. Thus, the LLR was task dependent rather than just automatic gain compensation from background central drive. The underlying mechanisms for this enhancement of these LLRs are not clear. However, age-associated alterations in neurological mechanisms, such as impairment in spindle discharge rate, excitability of the motor neurons, and possibly an amplified supraspinal set with age, are plausible explanations (Chung et al., 2005; Kawashima et al., 2004; Mynark & Koceja, 2002). LLRs have been suggested to make effective contributions in protecting the
limb against dynamic unpredictable force changes (Marsden, Rothwell, & Day, 1983). Older individuals seem to increase their descending drive to the antagonist muscles (hamstrings), which might influence the agonist LLR gain compensation for this task. Accordingly, it appears that the context of the task and, in this case, the background activity of the muscle not being stretched (hamstrings) appear predictive of the amplitude of the quadriceps LLR during this novel weight-bearing test. We need further studies to verify this effect across various perturbation amplitudes in both young and elderly groups.

Many studies have measured muscle-response characteristics under resting conditions or when the joint is unloaded (Shultz et al., 2000; Wojtys & Huston, 1994). The novelty of this study is that we used a dynamic weight-bearing task under loaded conditions, which also emphasized accuracy, to examine neuromuscular control of the lower extremity. The accuracy of the task was similar between the two participant groups before the perturbation. We view this as a strength of the study because it appeared that the central set was similar across participants before the perturbation. Introducing random perturbations during an SLS might allow injured or elderly individuals to learn motor patterns that increase knee stability to apply to novel situations of everyday life. Training programs using perturbations of the support surface have been shown to reduce the risk of continued episodes of the knee giving way and allow participants to maintain their functional status for longer periods of time (Fitzgerald, Axe, & Snyder-Mackler 2000). Thus, the application of destabilizing forces to the knee during treatment might enhance neuromuscular responses, which might lead to increased function. Further research is needed to carefully analyze the adaptive effects of practice on the LLRs and determine whether training is associated with improvements in performance during unexpected perturbations.

In summary, we found that elderly individuals require greater muscle activity and have similar error when performing a novel weight-bearing task. Furthermore, the elderly trigger larger LLRs of the quadriceps muscle group despite similar levels of background activity of the quadriceps, suggesting that pure gain compensation (background quadriceps activity) is not the mechanism. Future studies to determine whether LLRs are trainable with practice and influence knee injury with age are of prime interest to motor-control and rehabilitation scientists.

Acknowledgments

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References


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