Resistance Strength Training’s Effects on Late Components of Postural Responses in the Elderly

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The effect of resistance strength training on different phases of reactive postural responses to upright-stance perturbation was assessed in elderly women. Perturbation to body balance was produced by fast arm movements aiming at lifting different loads in either certain or uncertain contexts. Results from center-of-pressure analysis showed that lifting a light load under uncertainty led to more body sway than under certainty. Resistance strength training led to short periods of body sway in the compensation phase and to decreased variability in the stabilization phase of postural responses. These results suggest that neuromuscular adaptation from resistance strength training benefits late phases of postural responses to perturbation of body balance in the elderly.

Keywords: posture, balance, aging, resistance training

Increased postural sway in the elderly in comparison with younger adults (Abrahamova & Hlavacka, 2008; Maylor & Wing, 1996; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997) has been shown to be accompanied by decreased muscle strength (Sturnieks, St George, & Lord, 2008). Further investigation has evidenced that muscle weakness in the lower limbs in the elderly is associated with falls (de Rekeneire et al., 2003; Lord et al., 2003; Moreland, Richardson, Goldsmith, & Clase, 2004; Rubenstein, 2006; Skelton, Kennedy, & Rutherford, 2002). Falls in the elderly have been shown to be caused in many circumstances by failure to deal with unpredictable perturbations in activities of daily living, requiring fast postural responses (Berg, Alessio, Mills, & Tong, 1997; Roudsari, Ebel, Corso, Molinari, & Koepsell, 2005). Experimental investigation of the effect of unpredictable perturbation of postural stability in the elderly, such as those induced by displacement of the support base (McIlroy & Maki, 1996) or manual load release (Rogers, Fernandez, & Bohlken, 2001), indicates poor capacity of keeping center of pressure (CoP) away from the limits of stable balance in the elderly as compared with young people. A component that may underlie poor responses to unpredictable...
postural perturbations in the elderly is lack of appropriate muscle activation to perform reactive postural responses.

In activities of daily living, a potential source of postural perturbation is represented by situations in which an individual misestimates the weight of an object to be lifted, leading to inappropriate preprogramming of postural specifications. Because in those situations initial muscle contractions are preset based on the expected load, when the object is effectively lifted the ensuing postural perturbation has to be compensated for based on a more precise estimation of the actual object weight. Toussaint, Michies, Faber, Commissaris, and van Dieen (1998) evaluated postural responses to lifting loads in young adults, comparing contexts of certainty versus uncertainty about load. In the certainty context, the same load was lifted for several trials, while in the uncertainty context, load was unexpectedly reduced in some of trials. Results indicated that unexpected load shift led to increased postural sway, thus requiring stronger postural responses to reposition CoP within the area of balance stability (see also Kingma, Van Dieen, & Toussaint, 2005; van der Burg & van Dieen, 2001). In this regard, investigation of voluntary manual movements has shown that unexpected changes in the task lead to delayed responses in the elderly in comparison with younger individuals (Amrhein, Stelmach, & Goggin, 1991; Rossit & Harvey, 2008; Rubenstein, 2006). That delay in movement reorganization might be critical for recovery of balance stability after loss of body equilibrium. Scarce evidence, however, has been presented about reorganization of postural control in response to unexpected perturbation of stance in the elderly (see McIlroy & Maki, 1996, for an exception).

Decreased stance stability in the elderly has been shown to be prevented by resistance strength training (Ferrucci et al., 1997; Rooks, Kiel, Parsons, & Hayes, 1997). Positive effects of increased muscle resistance on the elderly’s balance might derive from increased capacity of muscle responses (Granacher, Gruber, & Gollhofer, 2010; Hakkinen, Kraemer, Newton, & Alen, 2001; Hakkinen et al., 1998), improved coordination between agonist and antagonist muscles (Hakkinen et al., 2001; Patten & Kamen, 2000), decreased variability of force production (Hortobagyi, Devita, Money, & Barrier, 2001; Laidlaw, Kornatz, Keen, Suzuki, & Enoka, 1999), and more effective recruitment (Patten & Kamen, 2000) and synchronization (Bemben & Murphy, 2001; Hakkinen et al., 1998; Semmler & Nordstrom, 1998) of motor units. Those muscle adaptations to resistance strength training are expected to be particularly beneficial for postural responses in situations of threatening perturbations to upright stance.

The current study aimed to evaluate the effect of resistance strength training on postural responses to predictable versus unpredictable perturbations to upright stance in the elderly. Training aimed to improve resistance strength not only in the muscles of the legs but also in the muscles of the trunk and arms, by assuming that balance stability is recovered after a perturbation through a contribution of large numbers of adjustments throughout the body. The experimental strategy of perturbing balance stability was used in the work of Toussaint et al. (1998), leading individuals to under- or overestimate a load to be manually lifted quickly while standing. By using that strategy, we approached an important source of loss of postural stability in daily living situations corresponding to intrinsic self-produced movements poorly programmed to deal with environmental requirements. In this situation, as in trips and slips, individuals have to rapidly reposition the center of
mass over the basis of support to recover balance stability. The experimental situation thus reproduces to some extent events leading to threatening loss of upright balance. Considering that previous investigation has already revealed the benefit of resistance strength training for postural control (Ferrucci et al., 1997; Rooks et al., 1997), an original issue approached in the current study was identification of the phases of postural responses benefited by resistance strength training. From this approach, not only short- but also long-term postural adaptation after a self-induced perturbation was assessed.

Method

Participants

Participating in this study were 26 women with an age range of 60–75 years ($M = 64.8$ years, $SD = 4.7$). Application of a modified Baecke questionnaire (Voorrips, Ravelli, Dongelmans, Deurenberg, & Van Staveren, 1991) immediately before and after experiment indicated that participants neither participated in extra regular physical activity programs nor increased their physical activities during the study. They declared having had 8–11 years of formal study in school. Inclusion criteria were absence of health disorders or medication consumption that might affect motor performance, as indicated by screening, and physical independence in the performance of several housekeeping tasks, as indicated by the Baecke questionnaire. The exclusion criterion was more than four absences during the period of training for the experimental group, but no participants were excluded. Participants were admitted into the study after signing an informed-consent form in accordance with the Declaration of Helsinki. Five participants withdrew during the course of the study.

Task and Equipment

The experimental task consisted of keeping stable bipedal upright stance with parallel feet while lifting a weighted wooden box ($23 \times 22 \times 15$ cm). The box had lateral grips on two opposite sides, with ergonomic inclination for a comfortable grasping with the right and left hands. The box was positioned on a height-adjustable support at approximately the hip level. Participants initiated each trial with their hands near the grips and, after a verbal prompt by the experimenter, they were to grasp and lift the box as fast as possible up to a physical marker 20 cm above the upper edge of the box. After reaching the target position, they were to keep the box raised for 5 s. During intertrial intervals, the box was placed out of participants’ view and repositioned a few seconds afterward. On most trials the box repositioned for the ensuing trial was the same, while on some it was replaced by another one identical in shape but of different weight. The task was performed on a force plate (AMTI, OR6-5 model) with sampling frequency of 100 Hz.

Experimental Design and Procedures

The experiment was divided into three phases: pretest, strength training, and posttest. To assess performance in response to postural perturbations pre- and posttest,
participants lifted loads of 1, 3, or 5 kg, in certainty or uncertainty contexts. In the certainty context, they performed six familiarization trials followed by three probing trials for each load in sequence. Participants were informed that the load would be the same across trials within a block. Sequence of loads was randomized across participants. In the uncertainty context participants were informed that the load might be unexpectedly increased or decreased in some trials. Load shift was made after three to five trials under a constant load of 3 kg, with modification to 1 or 5 kg. Three trials were performed for each situation of load shift. Twenty-seven trials were performed under each context, with order of contexts alternated between participants within each group. All trials were performed in two sessions on a single day. Intertrial intervals were approximately 10 s long, and every 12–15 trials participants were given a rest interval of 2 min. Each session was approximately 15 min long. Participants wore a safety harness connected to the ceiling to prevent falls.

For estimation of maximum force on each resistance exercise pre- and posttest, participants initially performed one set of 10 familiarization trials without load. In the sequence, load was progressively increased for a single maximum voluntary contraction. A rest period of 3–4 min was employed between trials, and no more than five trials were performed on each exercise. A scale of perceived exertion for resistance exercise (Robertson et al., 2003) varying from zero (extremely light) to 10 (extremely heavy) was presented to participants in each trial. Maximum force was determined by indication of a score of 10 on the scale.

During the strength-training phase, participants were randomly assigned to one of two groups: strength training (ST) and control (CO). The ST group (n = 12, mean age = 63.7 years, SD = 3.7) participated in a program of resistance strength training for a period of 14 weeks, with the purpose of developing muscle resistance strength of different flexor and extensor muscles of the lower limbs and the trunk. Training aimed at developing muscle resistance through both single- and multi-joint exercises of resisted flexion and extension movements of the hip, knee, and ankle muscles of both the right and the left side of the body, and also for bilateral muscles of the trunk and arms. A single exercise was selected for each muscle group, and the set of exercises was the same throughout the training program. Training was initiated with intensity of muscle contractions equal to 40% of the perceived maximum exertion during the first 2 weeks. In the following 14 weeks, load was increased to 60% of the perceived maximum exertion, with weekly adjustment of load. Training sessions included 10 min of walking, then muscle stretching, main strength training, and finishing with muscle stretching. In each session, participants aimed to perform three sets of 8–10 repetitions of each exercise, with rest periods of 2 min between sets. Sessions were 60 min long with a frequency of three times per week on alternate days. Movements were self-paced, with training only on weight-lifting machines. Although regular travel to the location of training and associated activities may also have contributed as a kind of physical activity for the ST group, they could hardly induce an effect on postural responses. In the same period, participants in the CO group (n = 9, mean age = 65.6 years, SD = 5.5) did not receive training and were instructed to perform their regular daily routine. In addition, the CO group attended monthly speeches about health and lifestyle. Thus, it is assumed that differences between groups are due to the experimental treatment rather than to associated activities. Both groups were tested on the experimental task immediately before training initiation and 2 days after the last session of training.
Analysis

Landmarks for the analysis of CoP sway in the anteroposterior direction are depicted in Figure 1. Onset time of box lifting to initiate a trial was determined by an abrupt rising of vertical force. The other landmarks of interest were anterior and posterior peak sway. To assess postural responses, CoP sway was segmented into three components. The first component corresponds to CoP excursion in the direction of the mechanical perturbation up to the point of its direction reversal (perturbation phase). Next, CoP moves to the opposite direction to compensate for the postural perturbation, in an attempt to reestablish a stable stance (compensation phase). The last component of the reactive postural response takes place with a number of body oscillations of small magnitude in an attempt to stabilize quiet stance (stabilization phase).

The following dependent variables were calculated: anterior-sway (perturbation period) amplitude and duration and posterior-sway (compensation period) amplitude and duration. To analyze CoP variability in the stabilization period, we calculated $SD$s during the 3-s period after peak CoP posterior sway.

Raw data were low-pass-filtered with a dual-pass fourth-order Butterworth filter with a cutoff frequency of 8 Hz. Data extraction and processing were done automatically through a Matlab (Mathworks) routine after visual data inspection. Trials for the load of 3 kg were discarded from analysis, and trials for the loads of 1 and 5 kg were averaged separately for the contexts of certainty and uncertainty. Assumptions for parametric analysis were assessed through the Kolmogorov-Smirnov test. Statistical analysis was made through four-way $2 \times 2 \times 2 \times 2$ ANOVAs with repeated measures on the last three factors.

![Figure 1](image)

**Figure 1** — Vertical force and center-of-pressure (CoP) anteroposterior (a-p) sway over time with identification of CoP landmarks of interest. $F_z$ = vertical force.
Post hoc comparisons were performed through Newman-Keuls procedures, and the measure of effect size through eta-squared. Significant differences are reported only in the following section.

**Results**

**Perturbation Phase**

Analysis of anterior-sway amplitude indicated significant main effects of load, $F(1, 19) = 180.40, p < .001$, $\eta^2 = .904$, and uncertainty, $F(1, 19) = 56.20, p < .001$, $\eta^2 = .747$, and a significant load-by-uncertainty interaction, $F(1, 19) = 44.90, p < .001$, $\eta^2 = .702$. The main effect of load was due to increased CoP anterior sway when lifting the load of 5 kg ($M = 4.43$ cm, $SD = 0.96$) in comparison with 1 kg ($M = 2.43$ cm, $SD = 0.99$). The effect of uncertainty was due to increased values under uncertainty ($M = 3.84$ cm, $SD = 1.19$) in comparison with certainty ($M = 3.02$ cm, $SD = 1.47$). Post hoc comparisons for the load-by-uncertainty interaction showed higher values when participants lifted the load of 1 kg under the uncertainty than under the certainty context, but no effect of uncertainty was observed when lifting the load of 5 kg (Figure 2, panel A).

Analysis of anterior-sway duration indicated a significant main effect of load, $F(1, 19) = 15.93, p < .001$, $\eta^2 = .455$, and a significant load-by-uncertainty interaction, $F(1, 19) = 41.61 p < .001$, $\eta^2 = .686$. The main effect of load was due to longer anterior sway for the load of 5 kg ($M = 0.51$ s, $SD = 0.19$) than for the load of 1 kg ($M = 0.43$ s, $SD = 0.24$). Post hoc comparisons for the load-by-uncertainty interaction indicated shorter periods of anterior sway when lifting 1 kg in the context of uncertainty than in the certainty context, while for the load of 5 kg the opposite relationship was observed, with the uncertainty context leading to longer times of anterior sway than the certainty context (Figure 2, panel B).

**Compensation Phase**

Analysis of posterior-sway amplitude indicated significant main effects of load, $F(1, 19) = 8.00, p < .05$, $\eta^2 = .296$, and uncertainty, $F(1, 19) = 126.76, p < .001$, $\eta^2 = .869$, and a significant load-by-uncertainty interaction, $F(1, 19) = 99.69, p < .001$, $\eta^2 = .839$. The main effect of load was due to higher CoP posterior sway when lifting the load of 1 kg ($M = 3.48$ cm, $SD = 2.07$) than with the load of 5 kg ($M = 3.00$ cm, $SD = 0.96$). The main effect of uncertainty was due to increased values in the certainty ($M = 4.07$ cm, $SD = 1.63$) than in the uncertainty ($M = 2.41$ cm, $SD = 1.12$) context. Post hoc comparisons for the load-by-uncertainty interaction showed higher values when lifting the load of 1 kg in the context of uncertainty ($M = 5.15$ cm, $SD = 1.53$) than in the context of certainty ($M = 1.81$ cm, $SD = 0.79$), while no significant differences were found between contexts for the load of 5 kg (Figure 3, panel A).

Analysis of posterior-sway duration indicated a significant main effect of load, $F(1, 19) = 44.94, p < .001$, $\eta^2 = .702$, and significant load-by-uncertainty, $F(1, 19) = 41.10, p < .001$, $\eta^2 = .703$, and group-by-test, $F(1, 19) = 5.31, p < .05$, $\eta^2 = .218$, interactions. The main effect of load was due to longer posterior sway when lifting the load of 5 kg ($M = 0.69$ s, $SD = 0.19$) than with the load of 1 kg ($M = 0.52$ s,
SD = 0.20). Post hoc comparisons for the load-by-uncertainty interaction indicated shorter periods of posterior sway when lifting 1 kg in the context of uncertainty (M = 0.42 s, SD = 0.14) than under certainty (M = 0.62 s, SD = 0.21), while no significant differences related with context were found for lifting the load of 5 kg. Post hoc comparisons for the group-by-test interaction indicated lower values in the ST than in the CO group in the posttest, while no significant between-groups differences were found in the pretest (Figure 3, panel B).
Stabilization Phase

Analysis of CoP sway variability indicated a significant main effect of uncertainty, $F(1, 19) = 27.82, p < .001, \eta^2 = .594$, a load-by-uncertainty interaction, $F(1, 19) = 46.59, p < .001, \eta^2 = .710$, and an interaction between all factors, $F(1, 19) = 4.50, p < .05, \eta^2 = .191$. The main effect of uncertainty was due to higher values in the
uncertainty ($M = 0.69$ cm, $SD = 0.30$) than in the certainty ($M = 0.16$ cm, $SD = 0.30$) context. Post hoc comparisons for the load-by-uncertainty interaction revealed more variability for lifting 1 kg in the uncertainty ($M = 0.69$ cm, $SD = 0.30$) than in the certainty ($M = 0.33$ cm, $SD = 0.11$) context, while no significant differences were detected between contexts for lifting the load of 5 kg. Decomposition of the four-factor interaction into its simple effects indicated significantly lower values in the ST group when lifting 1 kg in the posttest than with the respective load in the pretest in the context of uncertainty, whereas no significant differences between tests were found for the CO group (Figure 4).

**Discussion**

In the current study, we aimed to assess which phases of reactive postural responses to perturbation induced by lifting an unexpectedly changed load are affected by resistance strength training in elderly women. Results indicated that for load decrease, the context of uncertainty led to greater CoP sway than in the context of certainty. That effect was found in the three phases of postural responses: perturbation, compensation, and stabilization. A distinct effect was found for load increase, with similar postural sway between the contexts of certainty and uncertainty. More important for the purpose of this study, positive effects of resistance strength training were found in late phases of postural responses to stance perturbation. In the compensation phase, shorter periods of posterior sway in the trained than in the CO group were found in the posttest. In the stabilization phase, results indicated

![Figure 4](image-url)  
*Figure 4* — Sway variability in the stabilization of the strength-training group (ST) and the control group (CO) as a function of test, uncertainty, and load. SDs are represented by vertical bars, and asterisks mark significant differences.
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decreased variability of postural sway in the situation of load decrease in the context of uncertainty in the posttest compared with the pretest for the ST group only. These results indicate that resistance strength training might promote a benefit to reactive postural responses.

Effects of Uncertainty and Load

A noticeable effect found in our results was increased stance perturbation when load was unexpectedly lighter than in previous trials. Lifting an unexpectedly lighter load was revealed to be the most threatening situation to stable upright stance, affecting postural-stability recovery in the three phases of postural response. In that situation, increased amplitudes of CoP sway were associated with short times of sway duration, indicating high velocities of body oscillation. Uncertainty when lifting a heavier load, on the other hand, led to minor effects on postural-control reorganization. This finding suggests that compensatory responses to underestimation of a load, requiring increase of the forces originally planned, are more easily implemented than when a modification in the agonist–antagonist relationship is required. When lifting unexpectedly heavier loads the corrective action takes place in the same direction as the original motion by just increasing the gain of the agonist muscles used in a situation, in which no large-scale adjustments are required. In the situation of load overestimation, on the other hand, participants were induced to plan application of force to rapidly lift a load heavier than that actually encountered. As a consequence, not only faster than appropriate arm movements but also exaggerated anticipatory postural adjustments are expected to take place (cf. Kingma et al., 2005; Toussaint et al., 1998; van der Burg & van Dieen, 2001). To compensate for such movements disturbing stance stability, participants have to inhibit the exaggerated force applied with posterior postural muscles and activate antagonist anterior muscles of the trunk and legs differently from the preplanned response to compensate for increased backward postural sway. Thus, postural corrections for lifting unexpected lighter loads are expected to result from a modification of the original synergy between anterior and posterior muscles responsible for postural control to recover stance stability. The same principle has been evoked to explain increased difficulty for correcting fast manual movements for overshooting in aiming (Barrett & Glencross, 1989) and for movement reprogramming in interceptive actions (de Azevedo Neto & Teixeira, 2009). Results presented here suggest that increased difficulty in dealing with a change in the relationship between agonist–antagonist muscles in response to an unexpected perturbation also applies to automatic postural corrections.

Resistance Strength Training

Results from analysis of resistance strength training suggest improved postural responses in late phases of stance-stability recovery after large perturbations. The primary perturbation phase, however, was shown to be insensitive to the effect of training. An aspect to be considered in the interpretation of this result is that the early phase of postural reactions features fast automatic responses in the opposite direction of perturbation to bring the body back to a safe position on the base of
support. That component of the postural response requires recruitment of fast-twitch fibers of the agonist muscles and synchronous inhibition of antagonist muscles. It becomes apparent from our results, then, that the early component of reactive postural responses is not improved through training of slow resistance movements and might require specific training to enhance it. In this regard, investigation of the effect of power training on body balance has shown that using a low load associated with fast movements leads to improved body balance in healthy older adults (Orr et al., 2006). This kind of training with fast movements may be required to improve early muscle responses.

An original point in the experimental strategy employed in the current study was looking not only at early responses to postural perturbation but also at the following phases of reestablishment of stable stance. Our results suggest that resistance strength training improved postural responses in the compensation and stabilization phases in the most threatening situation of recovering stance stability when lifting an unexpectedly light load. A distinctive characteristic of both compensation and stabilization in comparison with the perturbation phase is that successful postural responses seems to be more dependent on appropriate coordination between activation of agonist and antagonist muscles, rather than fast muscle responses, to recover stable upright stance. Resistance strength training in the elderly has been shown to lead to neuromuscular adaptations that might underlie the postural responses reported here, such as improved coordination (Hakkinen et al., 2001; Hakkinen et al., 1998; Patten & Kamen, 2000) and reduced coactivation between agonist and antagonist muscles (Hakkinen et al., 1998). It is plausible that the reduced duration of the compensation phase in the posttest for the trained group is due to an improved coordination between anterior and posterior postural muscles. The critical issue in this phase is the capacity to rapidly bring the body toward a stable upright position, moving the center of mass away from the limits of postural stability. Improved intermuscular coordination might favor early activation of anterior and decreased activation of posterior muscles to rapidly recover postural equilibrium. From this perspective, improved muscle coordination might underlie the shorter time of the compensation phase in the trained group. Decreased variability in the stabilization phase for unexpectedly light loads after training is thought to be associated with decreased variability of force production derived from resistance strength training in the elderly (cf. Hortobagyi et al., 2001; Laidlaw et al., 1999). In the stabilization phase, reduced force variability is thought to benefit recovery of a stable fine-tuned relationship between anterior and posterior postural muscles in the attempt to reacquire stable upright stance. Because in this phase of the response balance sway is characterized by small body oscillations, less variable force production due to training might favor a more stable regulation of the muscle synergy for postural control.

**Conclusion**

Results presented here provide a preliminary insight into the components of postural responses to stance perturbation that are benefited by a program of resistance strength training in the elderly. Benefit of late phases of postural responses indicates that this usual way of muscle strengthening in physical activity programs for the elderly might help in body-balance stabilization after an unexpected perturbation,
which could help prevent falls in the elderly. However, resistance strength training seems to be unable to improve early reactive responses requiring fast and vigorous muscle contractions. To improve the early component of postural responses to perturbations threatening upright-stance, stability training of muscle power or specific balance exercises may be required. Additional studies are needed to explore the contribution of specific muscle groups to generating improved reactive postural responses to unexpected perturbations.

References


