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Research article

HORMONE REPLACEMENT AND STRENGTH TRAINING POSITIVELY INFLUENCE BALANCE DURING GAIT IN POST-MENOPAUSAL FEMALES: A PILOT STUDY

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ABSTRACT

This study examined the effects of hormone replacement combined with strength training on improving dynamic balance control in post-menopausal women. Thirty one participating post-menopausal women were divided into three groups (hormone replacement (HR), non-hormone replacement (NR) and control (CR) group). HR and NR groups were tested for muscle strength and balance control during gait, prior to training and following a six week lower body strength training program. Quadriceps muscle strength was evaluated as isokinetic peak torque ($60°\cdot sec^{-1}$) using a CYBEX NORM and balance control was evaluated by center of mass – base of support relationships and ground reaction forces during gait perturbations. Only the HR group showed significantly ($p < 0.05$) improved balance control during the initial phase of unexpected gait termination and single stance periods while walking across uneven terrain following training. The strength gains in the HR group tended to be greater than in the NR group over the six week training program, although neither group showed statistically significant increases. The CR group showed no significant differences between testing times. HR in post-menopausal females may enhance dynamic balance control when combined with a strength training program, even if no statistically significant gains in strength are achieved.

KEY WORDS: Estrogen replacement, gait, balance, strength.

INTRODUCTION

Menopause is associated with significant reductions in circulating estrogen levels in females (Shephard, 2002). It has become increasingly clear over the last several years that estrogen plays an important role in the maintenance of many tissues and organs including skeletal muscles, nerves and neural tissues in females (Tarnopolsky, 1999). In particular, a number of studies have suggested that estrogen may play an important role in maintaining muscle strength, enhancing muscle repair and maintaining neurological function in older females (Skelton et al., 1999; Tiidus, 2002; Wise et al., 2001). Hence the post-menopausal reduction in circulating estrogen levels typical of older females may have implications for age-related declines in muscle strength and function, mobility, adaptations to training, propensity for falls and balance control. These changes may have profound implications for the long-term health, independence and quality of life for older women. Annually, one third of post-menopausal women experience a significant fall (Randell et al., 2001). The projected age groups affected are not just the 65 and older group, but an equal percentage affected will be between 45 and 64, these people being situated in the active labor force. Any inability to maintain upright stability that results in a fall and potential for a subsequent fracture exposes the individual to the medical, socioeconomic, physical and psychological effects associated with having a fall. There is evidence to suggest that significant numbers of older persons also have balance impairments, presumably via central nervous system and neuromuscular changes which may be due in part to estrogen loss (Naessen et al., 1997; Hammar et al., 1996). However not all research confirms such a direct link (Sipila et al., 2001).

The long term use of hormone replacement therapy in post-menopausal females has declined in the past several years due to recent finding of potential increased health risks and the limited effect of hormone replacement therapy as a chronic disease prophylactic (Wathen et al., 2004). However, its short term use, primarily to alleviate menopausal symptoms in low risk women remains popular and medically accepted (Wathen et al., 2004)

Although not a consistent finding (Bemben and Langdon, 2002), studies have suggested that estrogen may enhance and maintain muscle strength in human females (Sarwar et al., 1996) and its loss may be related to strength declines associated with aging in older females (Phillips et al., 1993; Skelton et al., 1999). Thus the menopause related loss of estrogen could predispose females to further strength losses (Roth et al., 2000; Tiidus, 2002).

Further, a close relationship exists between changes in muscle strength, balance and susceptibility to falls in older adults (Wolfson et al., 1985). Therefore it is possible that post-menopause estrogen replacement may be a factor in maintaining muscle strength and enhancing muscle trainability and thus be important in maintenance of static and dynamic balance and the potential risk of falls in older females. Previous studies have tended to examine effects of HRT on body composition (Teixeira et al., 2003), strength (Skelton et al., 1999), or balance (Salmen et al., 2002) without usually attempting to link these potential changes together. Previous studies have also had mixed results with some reporting enhanced influence of HRT on strength gains, enhanced lean body mass or balance (Salmen et al., 2002; Sipila et al., 2001; Sipila and Poutamo, 2003), while others failed to find such relationships (Bemben and Langdon, 2002; Teixeira et al., 2003). The few previous studies that have addressed the issue of relationships between muscle strength, strength training and estrogen in post-menopausal females have usually used only simple measures of balance (Asikainen et al., 2004). More robust measures of dynamic balance, which are more ecologically realistic and functionally relevant, could add further information regarding any relationships between balance, HRT use and/or strength training in post-menopausal females.

This preliminary study examined the relationship between estrogen and dynamic balance improvements in hormone replaced (HR) and non-replaced (NR) post-menopausal females following a brief (6 week) lower body strength training program. In particular, this study attempted to discern if a relationship between HRT, strength training and a more robust and realistic measure of dynamic balance, as employed in this study could be demonstrated. The results of this pilot study could then help determine directions for further research in this area.

METHODS

This investigation was approved by the Wilfrid Laurier University Human Ethics Committee. Post-menopausal females were recruited for each experimental group (using hormone replacement (HR) (n = 10, mean age = 55.5, mean ht = 1.65 m, mean wt = 69.0 kg), and not using hormone replacement (NR) (n = 12, mean age = 56.9, mean ht = 1.66 m, mean wt = 71.0 kg)). An age-matched control (CR) (n = 9, mean age = 56.0, mean ht = 1.66 m, mean wt = 74.3 kg) group was also used. Each group started with n=13; some attrition of subjects occurred in the study leading to unequal numbers in the groups. The control group consisted of 4 women using HRT and 5 who did not. This group was used only to control for any natural progression in balance control and strength measures over time and since no significant changes were observed between HR or NR women in this group, the results were combined into a single control group. The form of HR replacement was not specifically determined, as the only variable we were initially interested in for this preliminary study was circulating estrogen concentration. All study group and control group subjects were administered an exclusion questionnaire. The exclusion criteria included: any drug use that affects balance; any neuromuscular, joint or sensory disorders; any illness, injury or surgery affecting the whole-body or arm/leg movements, a history of dizziness or a medical condition which precludes resistance training. Only subjects who had not been engaged in systematic resistance training for lower limbs for at least 2 years prior to the initiation of the study were selected. Subjects were also asked about their current menstrual/menopausal status, their estrogen replacement status, as prescribed by their physician and assigned to appropriate groups accordingly. Subjects selected for the HR group were generally post-menopausal and had been taking hormone replacement for at least 6 consecutive months prior to the start of the study. Subjects assigned to the NR group were also similarly post-menopausal and had not have been taking estrogen supplements for at least 6 months prior to the start of the study. With the exception of two of the subjects (who were about 6 month beyond their last menstrual cycle) all subjects were more than 12 months beyond their last menstrual period and the large differences in circulating estradiol levels between groups, without individual overlap assured that we were using subject populations with distinctly different levels of exposure to estrogen. Circulating estrogen status was confirmed by a blood test. Circulating serum estrogen (as estradiol-17β) concentration as determined from a 3.0 ml blood sample drawn from the brachial vein. Blood was allowed to coagulate and the serum separated via centrifugation. Estrogen concentration was determined via radioimmuno-assay-(TKE21, Diagnostic Products, Los Angeles Ca) (Stupka and Tiidus, 2001). Prior to the beginning of testing, each subject engaged in the collection of standardized measurement of anthropometrics (height, weight) and health status relative to potential risk in participating in physical activity. The latter was determined via simple standard questionnaires (including ParQ for older adults). Subjects who had no positive responses in the ParQ test were selected for the study. Also some subjects who may have had one positive response to the ParQ test and were subsequently cleared by their physician to participate in physical activity were also selected to participate. Strength testing involved dynamic isokinetic concentric (60 degrees·sec^{-1}) peak torque determination (in newton meters) of quadriceps (knee extensors), muscles forces using standard testing protocols on the CYBEX NORM Dynamometer apparatus (Sale, 1991). One familiarization session for the strength testing protocol was provided for each subject prior to the start of the experiment. Subsequently at the start and end of the experiment, subjects were given 3-4 trials separated by 30-60 seconds to assess peak quadriceps torque. The best trial was used as the measure of peak torque in each subject. In addition, the progression of increasing weight lifted in each exercise over the six week training period was recorded for each subject.

Testing of balance control involved recording biomechanical responses during two perturbation protocols: gait termination (Perry et al., 2001) and gait over uneven terrain (Perry et al., 2004). The first protocol, gait termination, provides an indication about how efficiently an individual can make the transition from a whole-body steady-state dynamic movement (walking) to a static position (standing) without preplanning. While walking at a comfortable pace along the walkway, subjects were signaled (by means of an auditory buzzer) to terminate gait suddenly, without warning, in 25% of the trials. The second perturbation protocol involved evaluating the ability of the subject to negotiate uneven terrain during gait by placing a series of inclined platforms along the length of the walkway. The platforms were placed in such a way that the foot contacted a different platform at each step. During each gait trial, subjects walked at a comfortable pace over the inclined platforms. They were instructed to look straight ahead at an X marked on the wall. Each platform had an angle of 10 degrees across a distance of 45 cm. For each consecutive trial, the orientation of the two inclined platforms positioned over the force plates was randomly changed to elicit natural responses to unexpected changes in terrain.

Kinematic data was collected using two OptoTrak 3020 (Northern Digital, Waterloo, ON) camera banks. A sampling rate of 100 Hz was used and 12 infrared light-emitting diodes (IREDs) were utilized to monitor the motion of the whole body (Figure 1). A 7 link-segment model was used to calculate the total body COM using anthropometric data compiled by Winter (Winter, 1990).

Horizontal and vertical ground reaction forces were measured at each foot using 3 force platforms (Advanced Mechanical Technologies, Inc., Watertown, MA). Force plate data, synchronized with the kinematic data, was sampled at 200 Hz for 5 seconds.

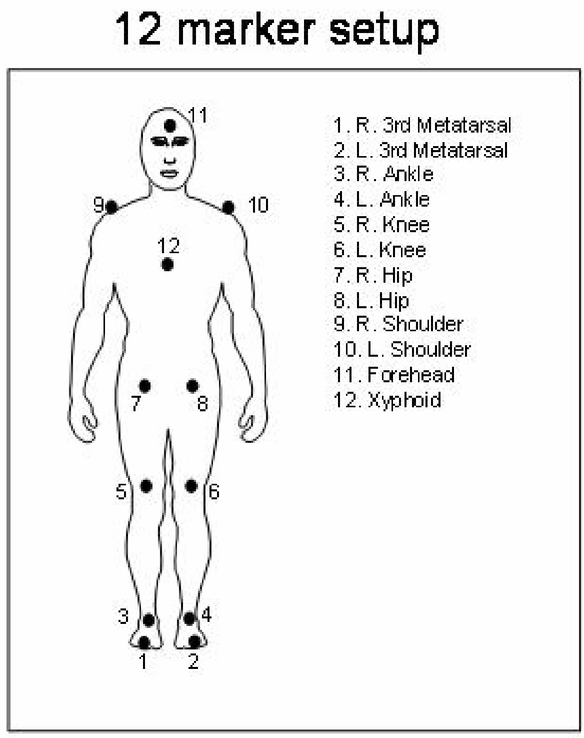

Figure 1. Marker setup for kinematic data collection and calculation of center of mass.

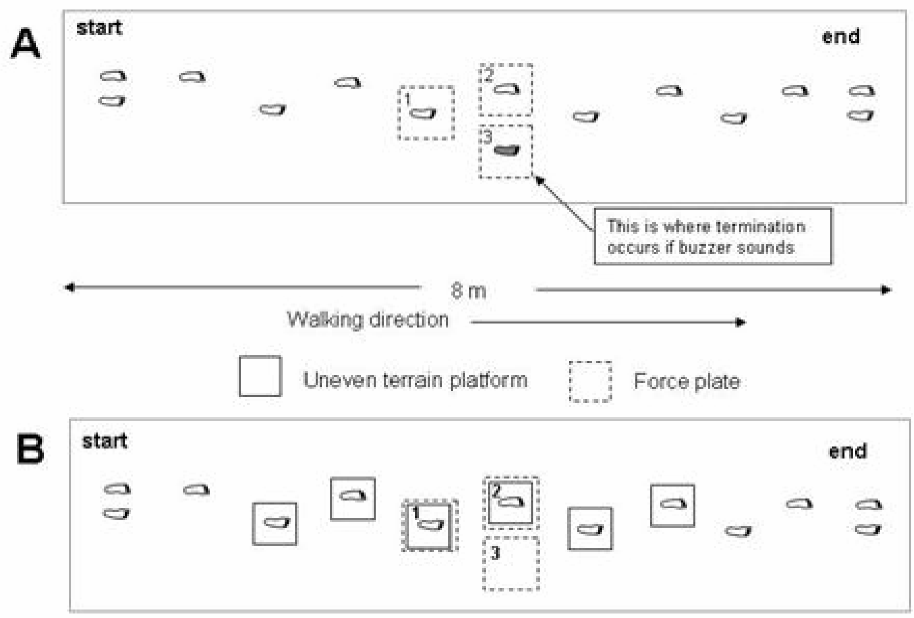

Figure 2. Walkway setup and force platform positions for the gait perturbation protocols. **A**. For gait termination participants were either signaled to stop (as indicated) or continued to walk to the end of the walkway. **B.** Uneven terrain protocol. The solid squares indicate the positions of the inclined platforms for the uneven terrain protocol.

All trials were performed along an 8-m walkway which had three force plates embedded in the floor, making them at the same level as surface of the walkway (Figure 2). The force plates were positioned so that during termination trials the subject terminated gait on plates two and three (Figure 2A). During the uneven terrain gait trials, the subject stepped on inclined platforms positioned over plates one and two (Figure 2B).

The primary outcome measures involved the center of mass - base of support (COM-BOS) relationship and force production during loading and unloading of the plates. The COM-BOS relationship was evaluated throughout the gait termination and gait over uneven terrain trials as the relative distance of the COM from the BOS (one or both feet in contact with the ground) [Figure 3 shows examples of the measurements displayed in Figures 5 (gait termination) and Figure 7 (uneven terrain)]. The COM-BOS measurement allows for us to determine the proximity of the COM to the limits of the BOS during walking. These measurements provide information about the person's ability to effectively establish a stability margin (or their ability to respond appropriately so that the COM does not approach too close to the BOS limits as to threaten balance during walking) or their ability to allow the COM to be positioned further away from the BOS during single support (evidence that the individual is capable of generating more muscle force to maintain balance). Force loading and unloading rates (for 100 ms) were calculated when the foot contacted and lifted off of the force platforms respectively. This measure provides an indication of force loading patterns used to control the body's motion (e.g. during gait termination it indicates the rate of force development that is generated to slow the body in order to stop walking).

Resistance training & subsequent testing

Following the initial tests of strength and balance control, the subjects HR and NR groups began a 6-week, 2 days/week progressive resistance training programs for the lower body. The CR group did not participate in the training program. The program was based on the American College of Sports Medicine guidelines for progression models in resistance training for healthy adults (Kraemer et al., 2002). The training program involved 8 different resistance exercises of both isolated muscle and combined muscle groups designed to build strength in lower limbs. Exercises included seated knee extension and flexion exercises, seated leg press, standing ankle extension exercise, hip adductor and abductor exercises, and lunges holding dumb bell weights This training program was lead and supervised by a fitness training professional who designed individual progression programs for each subject (beginning with 1-2 sets of 8-12 RM for each exercise and progressing to 3 sets with increased resistance as appropriate). Progression was typically predicated on the subject being able and willing to perform more than 10-12 repetitions on the final set and occurred between every 1-3 weeks in individual subjects. The training program utilized "Universal Gym" exercise machines and free weights available in the Wilfrid Laurier University athletic complex. Subjects were

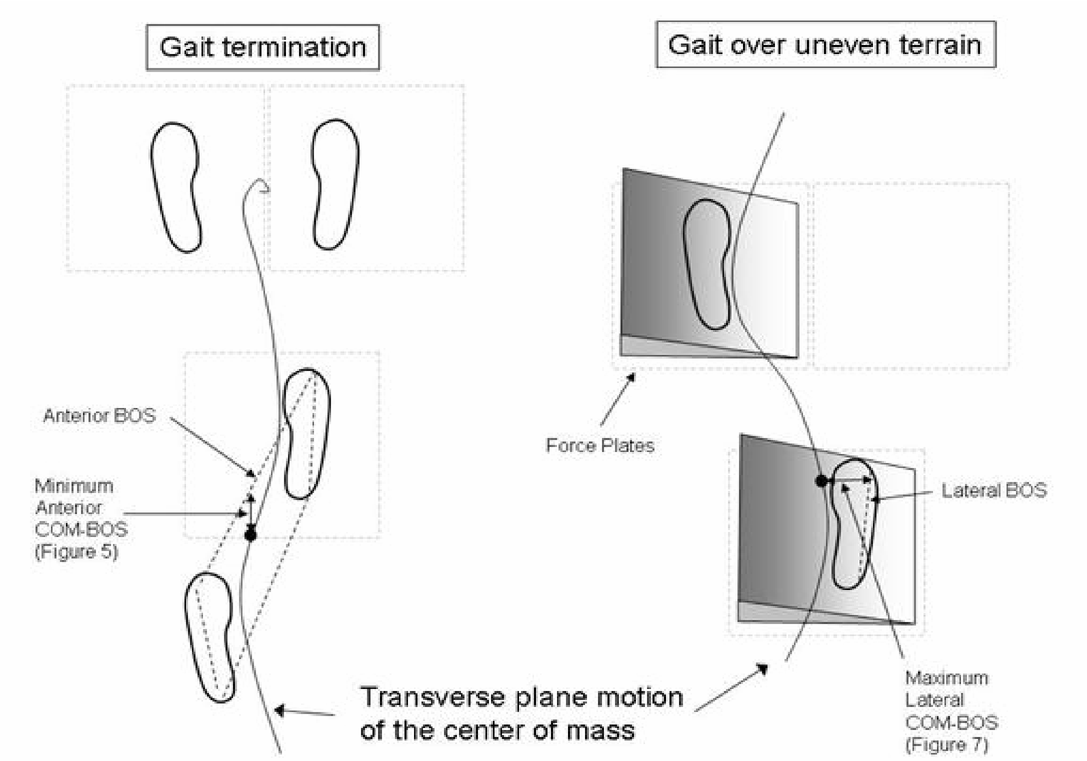

Figure 3. Schematic representation of the center of mass – base of support (COM-BOS) relationship calculations that represent the significant findings in both gait termination and gait over uneven terrain.

instructed to keep a log of their training sessions and progression. A minimum of 80% attendance at training sessions was required for the subjects to remain in the study. The initial session was used to teach the subjects appropriate technique and to determine their appropriate training resistance for each lower body exercise. Subsequently they began the 6 week program. Six weeks of strength training, while relatively short is typically sufficient to induce increases in muscle strength in untrained individuals (Sale, 1988).

Between 1 - 3 days subsequent to the completion of the 6 week training protocol, strength and balance control testing protocols were repeated for the HR & NR groups to assess the influence of training on muscle strength gains and static and dynamic balance/gait indices. The CR group was also retested at this time to evaluate any changes in the outcome measures as a result of the passage of time or learning effect.

Statistical analysis

A two-way (pre/post x group) repeated-measures analysis of variance (ANOVA) was used to determine within-subject and between subject effects on the strength and balance response measures. Subsequent to a significant ANOVA ($p < 0.05$), a Tukey post-hoc test was used to determine significant group effects at an a priori p level of 0.05. Outliers were determined by identifying measures that were outside 2 standard deviations of the variable mean. Then data for that trial was inspected for technical or other (e.g. missed force plate contact, marker missing) problems that would cause an error in measurement, and if no reason for exclusion was determined then the data was retained for analysis. Video recordings of trials were used to determine that proper force plate contact was made. There were 41 out of 930 trials (<5%) that were excluded for a missed steps or the participant did not terminate gait correctly on the force plates when the audio buzzer was triggered.

RESULTS

The mean blood estrogen concentration was significantly higher ($p < 0.001$) for the hormone replacement group (HR); 101.0 ± 42.9 pg estradiol·mL^{-1}, versus the Non-hormone replacement group (NR); 11.9± 5.6 pg estradiol·mL^{-1}. No overlap in estradiol levels between any individuals in the NR versus the HR group was present. The control was not tested for estradiol level.

None of the three (CON, HR or NR) groups achieved a statistically significant increase in any of the strength measures (i.e. Figure 4). However, a slight tendency towards an increase in strength from pre-training to post-training was more evident in the HR group in knee extension (1.71 Nm·kg^{-1} vs. 1.94 Nm·kg^{-1}; $p = 0.114$, Figure 4). The changes in strength seen in the NR group did not show any

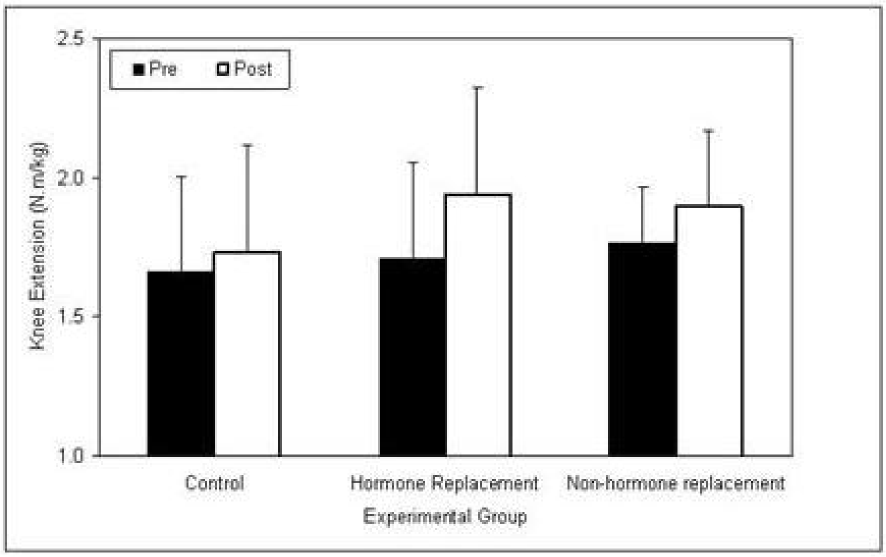

Figure 4. Dynamic isokinetic concentric (60 degrees·sec^{-1}) peak torque of the quadriceps (knee extensors) pre-training versus post-training for the three groups [control (CR), Hormone Replacement (HR) & Non-hormone replacement (NR)].

significance or indications as trends (1.77 Nm·kg^{-1} vs 1.90 Nm·kg^{-1}, p's > 0.4). These pre- versus post-training changes in knee extension strength represented an average 13.5% increase in the HR group versus and average 7.3% increase in the NR group, which was not statistically different.

Improvements in the amount of weight used for training tended to be higher in the HR group then in the NR group but were not statistically different (p > 0.05). An example of the general degree of progression in training can be seen in leg press (HR 18.7% Weight Increase vs. NR 10.6 %). This suggested that the rate of progression in weight lifted during training as not being significantly different between HR and NR groups.

For balance variables indicated below there was a significant group x pre/post interaction effect. During gait termination the HR group demonstrated a significant decrease (pre versus post training) in the amount that the center of mass moved towards the anterior base of support (as indicated by an larger minimum anterior COM-BOS difference) during the first double support phase (0.311 cm vs. 0.350 cm; p = 0.039; Figure 5). This is the phase when the signal to terminate gait occurred. The control and NR group showed no significant change in this variable.

During gait over uneven terrain, when the foot initially contacted a forward sloping platform, the HR group showed a significant (5.78 kN·s^{-1} vs. 7.02 kN·s^{-1}; p = 0.003) increase in the rate of vertical loading

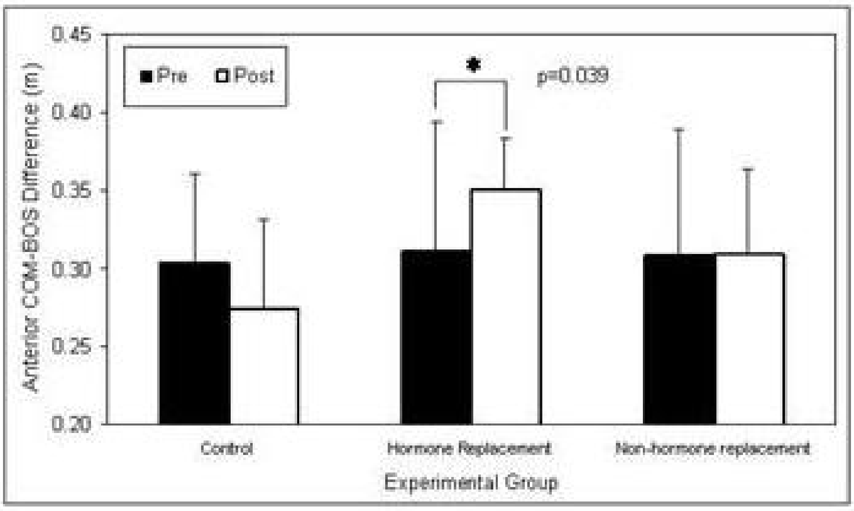

Figure 5. Minimum COM-BOS difference relative to the anterior border of the lead foot during the double support phase when the audio signal to initiate gait termination was activated. Differences are expressed for pre-training versus post-training for the three groups (CR, HR & NR see figure 4 for abbreviations).

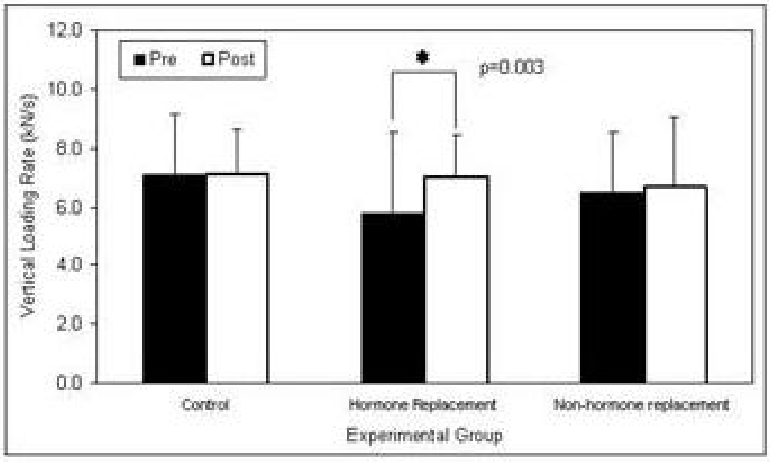

Figure 6. The rate of vertical loading force when the foot initially contacts a forward sloping platform. Values are expressed for pre-training versus post-training for the three groups (CR, HR & NR see figure 4 for abbreviations).

force (Figure 6). No significant changes occurred with the control or NR groups. Additionally, the HR group showed a significant increase in the maximum COM-BOS difference (0.288 cm vs. 0.325 cm; p= 0.03; Figure 7) in the medial-lateral direction during single limb support, whilst the right foot was supported by a platform slanted downward from left to right, when compared to the pre-training values.

DISCUSION

The use of hormone replacement in post-menopausal women may have both positive and negative affects on hormone regulation, osteoporosis, cardiovascular function and overall health. This study examined the role of hormone replacement in improving a robust and functional measure of dynamic balance (gait) following a brief strength training program. Most interestingly, the HR group demonstrated significant improvements in specific measures of dynamic postural control during gait while the NR group exhibited no such improvements. These improvements in dynamic balance observed in the HR group occurred despite a lack of statistically significant increase in measures of muscle strength. Since the training program in this pilot study only consisted of 12 sessions, it may not have been of sufficient stimulus to induce a statistically determinable improvement in strength gains. However, tendencies favored strength improvements in the HR group.

Nevertheless, even minor enhancements in muscle strength, in the HR group, possibly combined with other neuromuscular influences of estrogen [e.g. attenuation of the extent of neural cell death, see

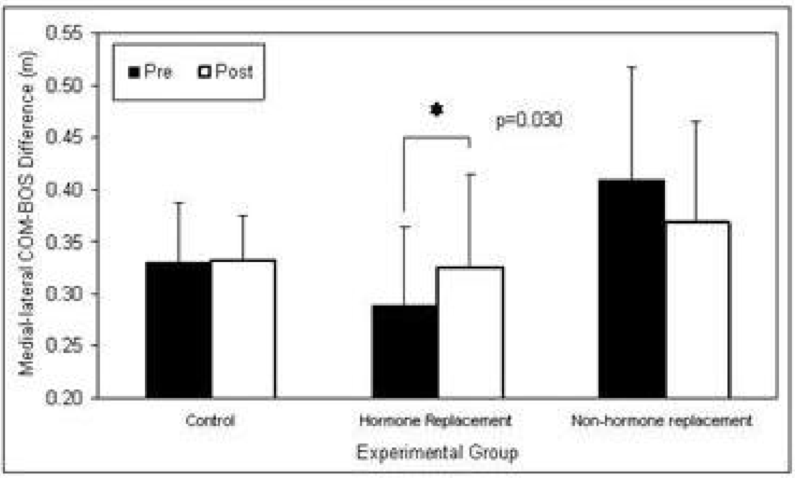

Figure 7. Maximum COM-BOS difference relative to the lateral border of the foot during right single support on a platform slanted downward from the left to right side of the person. Differences are expressed for pre-training versus post-training for the three groups (CR, HR & NR see figure 4 for abbreviations).

review (Wise et al., 2001)] may be responsible for the changes in balance control observed in this study. During gait termination the increase in the COM-BOS difference in the anterior-posterior direction, which indicates that less forward progression of the body took place after hearing the audio signal, would be accomplished by producing extensor support moments in the lead limb to affectively slow the forward momentum of the body. This could be due to a greater knee extensor (albeit not statistically significant) strength improvement seen in this group, since the other groups (NR and CR) did not show either a balance or strength change. Alternatively, the extensor support moment could also have been generated at the hip or ankle. Both of these joints were trained, however any change resulting from the training program was not specifically tested in this study.

Additionally, during gait over uneven terrain when the HR group was in single stance on a laterally sloping platform they were able to increase their ability to balance (medial-lateral COM-BOS difference) after strength training. The fact that the NR group was higher then the other two groups may have produced a ceiling effect (no improvement possible) in this group when considering this outcome measure. The HR group also produced vertical force at a quicker rate when they initially stepped on a forward slanting platform, which may indicate that the training has allowed for quicker and more powerful reactions to these gait perturbations after strength training. This improvement in speed and power is based upon studies (Hakkinen et al., 2001; Sipila and Poutamo, 2003) that indicate physical training with or without hormone replacement therapy can improve explosive power of the lower limbs in older women.

Some other potential reasons for changes in dynamic balance control could stem from the possibility of improvements from physical activity such as improved motor control or balance confidence (Lord et al., 1996). With greater exposure to weight bearing and strengthening exercises there has been evidence presented that an individual can improved their body awareness and possibly improve neural functioning just from performing the physical activity [i.e. Tai Chi, (Wolf et al., 1996)]. The improvements in the balance measures reported in this study would potentially only come into play when the person's balance is disturbed. If balance were perturbed, with the reported improvements in balance measures, the subjects should now be able to produce more force when reacting to the perturbation and so better stay within their BOS limits and thus be less susceptible to falls.

Previous studies have tended to examine either the; 1) effects of HRT or estrogen on strength or body composition following weight training (Skelton et al., 1999; Teixeira et al., 2003), 2) effects of HRT or estrogen on balance (Salmen et al., 2002), or the effects of strength training on balance (Latham et al., 2004) alone. This preliminary study is one of the first to attempt to link these issues into one study. Previous studies have also had mixed results, with some reporting enhanced influence of HRT on strength gains, enhanced lean body mass or balance (Salmen et al., 2002; Sipila et al., 2001; Sipila and Poutamo, 2003), while others failed to find such relationships (Bemben and Langdon, 2002; Teixeira et al., 2003). While this study failed to find a significant difference in strength gain between HR and NR groups, an interesting difference in balance control following training between HR and NR groups did emerge. This study cannot yet confirm a functional difference in balance control between HR and NR groups following training but the data is sufficiently interesting to warrant further longer term study to confirm this theory.

This preliminary study was limited by the relatively short length of the strength training period, the relatively small number of subjects used and the relatively few dynamic balance and strength gain measures performed. Future studies will need to address these deficiencies in order to confirm the potentially interesting findings related to strength training and dynamic balance gains in post-menopausal females seen relative to HR in this preliminary study.

CONCLUSION

In conclusion, this preliminary study demonstrated that even a short modest strength training program which did not induce statistically significant improvements in muscle strength could preferentially enhance indices of dynamic balance during gait trails in post-menopausal HR females while having no effect on NR females. The mechanisms for this differential effect cannot be elucidated from this study. Nevertheless, these findings have important potential implications for post-menopausal females and further studies of the influence of strength training, HRT and balance control in this cohort are warranted.

Future work should focus on the following: 1) the relationship of HRT and balance control; 2) the investigation of other dynamic balance or functional tasks within this group; and 3) other training protocols (power training, reaction times or balance training) that may help to determine if the changes seen here are attributed to strength, power or control.

If potential benefits of hormone replacement therapy extend to enhancing muscle strength gains from appropriate training during the period of hormone replacement therapy use in post-menopausal women, this information may be important for future exploitation of this opportunity window to initiate and optimize such strength gains specifically in this cohort. Such targeted training interventions could then potentially be promoted during the periods of prescribed hormone replacement therapy use in appropriate individuals to maximize their muscle strength and power gains and hopefully transfer these gains to improvements in functional abilities, reduced injury risk and delayed onset of frailty. Specific research data regarding optimal interventions for this cohort would greatly strengthen the targeted intervention potential for this cohort among health professionals.

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KEY POINTS

- This study provides evidence that even a short modest strength training program can enhance dynamic balance control in older adult females taking hormone replacement.
- If potential benefits of hormone replacement therapy extend to enhancing muscle strength then this would be important in designing optimal interventions for both strength and balance for this cohort.
- Future work should explore the influence of hormone replacement therapy on other dynamic balance or functional tasks.

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