Effectiveness of Water Exercise on Postural Mobility in the Well Elderly: An Experimental Study on Balance Enhancement

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Background. The fear of falling may cause elderly people to limit their movement. As movement errors are known to facilitate the acquisition of motor skills, the elderly may inadvertently cause the loss of postural skills by constraining their movements, and hence avoid potential movement errors. It was hypothesized that by having elderly individuals exercise in a risk-free environment — water was utilized in this experiment — their postural capabilities would improve.

Methods. Four groups of elderly subjects (80 ± 5.8 years old) were placed into four groups: Water Exercisers; Land Exercisers; Water Sitters; and Land Sitters. Each group met twice per week for 45 minutes for 5 weeks of simple exercises or socializing in the designated medium. The distance each individual could reach (Functional Reach, FR) was measured at the end of each week.

Results. Initially, each group was at risk (FR < 10 inches) for falling. Statistical testing showed that the Water Exercisers (WE) increased their FR almost every week; the Land Exercisers (LE) increased only during the first week; and the Water Sitters (WS) and Land Sitters (LS) did not increase at all. The FRs after 5 weeks were 13.4 ± 1.6 (WE), 11.3 ± 1.5 (LE), 9.6 ± 1.3 (WS), and 9.3 ± 0.71 (LS) inches for each group, respectively.

Conclusions. The data showed that the postural capabilities in these elderly people, as measured by the FR, were enhanced by the production of movement errors that was facilitated in a water environment (in the case of the Water groups) or the initiation of a novel exercise program (Land Exercisers). Alternative explanations, and implication of these results, are discussed.

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FALLS in the elderly population are a well recognized health problem (1−3). A variety of studies have addressed this problem by looking at possible pathologies (4,5), at risk factors (2,3,6−8), and rehabilitation strategies which address potential pathologies or risk factors (9−11). The present work addresses fall prevention in the elderly by looking at the cause of poor balance as a self-induced motor skill loss. Thus, training is done through the application of principles that have been determined through motor skill acquisition research.

Due to the prevalence of, and morbidity and mortality associated with falls in the aged population, the elderly individual tends to restrict his/her mobility so as to prevent the occurrence or recurrence of a fall. By limiting activity, the elderly person may become trapped into a vicious cycle (Figure 1) of voluntarily restricting activities, which in turn causes a decrease in functional mobility, which results in limited activities, at which point the whole process recycles (3,8).

By constraining movement, the number of correctable movement errors which occur will decrease; if the person does not move, he/she will not experience novel movements. This reduction in errors will be evident not only in the absolute number of errors, but also in the movements and environmental settings that will produce these errors. Furthermore, given the reduced sensory capabilities found in the elderly (for example, 4,12−14), it would be anticipated that the absolute magnitude of the movement errors would need to be large in order for the errors to be perceived and subsequently corrected.

Movement errors have been well documented as the guidance for motor skill acquisition (for reviews see 15,16). Similarly, the failure to make postural movement errors may lead to a loss of skill in performing postural tasks. Thus, elderly persons’ limited mobility may cause a progressive reduction in their postural capacity by their failure to produce errors while practicing these skills.

Postural tasks are unlike many other motor skills, for the consequences of failing to correct a postural error can produce an injury resulting in the “fear-of-falling” that many elderly individuals express (17,18). Thus, if postural skills are to be practiced, they must be done in a safe environment. Duncan, Weiner, Chandler, and Studenski (19) reported that subjects who would only reach a short distance unsupported could reach farther when placed in a protective, non-weight supporting harness. Similarly, Piller, Dickstein, and Zui (20) found that patients with cerebral vascular accidents had a quantitatively more normal gait pattern when harnessed, even though the harness did not provide weight relief.

In the present research it was hypothesized that the elderly would be more willing to move if in a safe environment; for this study, water was chosen as the safe medium. This increase in movement would produce more movement errors,
which would guide the development of postural control mechanisms. Improvement in these mechanisms would be evident in an increase in the subjects’ Functional Reach (FR) (19).

Several alternative hypotheses to the primary hypothesis were apparent. First, exercise has been shown to enhance balance control (9-11). Second, water’s therapeutic benefits have been commonly ascribed to its physical properties, such as buoyancy, pressure, and thermal exchange (21-23). Finally, socialization has been suggested as a means of increasing physical activity (24). To demonstrate that the effect of water exercise was through its influence on error production, these alternative hypotheses were concurrently tested.

METHODS

Subjects
Fifty-two independently living elderly volunteers (80.0 ± 5.8 years, range 74–90 years old, 7 males, 45 females) were recruited from a residential retirement community in Phoenix, Arizona. The requirements to live in the retirement community were that an individual be 65 years or older, be an independent ambulator with or without an assistive device, and be independent with activities of daily living. All subjects read and signed an informed consent prior to participation. Subjects also filled out a medical history questionnaire which was reviewed to identify any high risk subjects. None of the participants was found to be at high risk. Therefore, no subject was excluded for medical reasons. Subjects who missed more than three exercise sessions were excluded from analysis.

Groups
Participants were randomly assigned to one of four experimental groups of 13 subjects each. These groups were designed to isolate the effects of exercise, water immersion, and socialization, from pool exercise. They were descriptively called:

1. Water Exercisers; those who exercised in the pool.
2. Land Exercisers; those who exercised on the land.
3. Water Sitters; those who sat in water without exercise but with supervised socialization.
4. Land Sitters; participants who played cards in an activity room with supervised socialization.

All groups met separately for 45 minutes, twice per week, for 5 weeks under the supervision of the experimenter (VS).

Experimental Tasks

Exercise tasks — land and water groups. — The exercise regime, done to subject tolerance with rest periods as needed, was identical for the water and land exercise groups. Ten repetitions of standing tasks and four repetitions of 6.1 m (the maximal cross pool distance) for walking tasks were requested. The participants were asked to complete the activities to individual tolerance and with the minimal amount of assistance required to complete the activities. Assistance was provided to complete the activity on an as-needed basis when requested by the participant. The specific exercises were:

- walking forward and backward
- walking backward while high stepping
- marching forward and backward with knees bent
- walking forward and backward with knees straight
- sidestepping without crossing the legs
- sidestepping with crossing the legs
- heel-to-toe walking forward and backward
- marching in place
- standing partial squats
- toe raises
- heel raises
- kicking in a diagonal
- kicking in cardinal planes of motion
- twisting

The water exercisers exercised in an outdoor pool and the land exercisers exercised indoors in a large, carpeted empty church congregation hall. The pool temperature was 29.4–32.2 °C; pool area was 6.1–15.2 m. Its depth went from .9 to 1.5 m over the 15.2 m length. Subjects exercised in 1 to 1.4 m of water depending on their height and stability in the water (the water level was between their waist and nipple line). Land exercisers could hold onto the back of a church pew to attain stability.

Non-exercise tasks — land and water groups. — The water sitters sat in the same pool to a level similar to the water exercisers (between waist and nipple line) and were asked to socialize among the group. No other people were in the pool except the experimenter (VS).

The land sitters were involved in card playing activities while sitting at a table and were supervised by the experimenter (VS).

Data Collection

The FR test (1,19) was utilized to assess each participant’s stability. The average of three consecutive reaches was recorded prior to the experiment, and following the last session of each week by the first author (VS). Data were recorded in terms of absolute positions (i.e., initial = 20, final = 35). The calculation of the reach (i.e., reach = 15)
was done after the conclusion of the study to minimize potential experimental bias that would affect the data collection. To maximize treatment and test consistency, the second author (PH) observed sessions with each group halfway through the study.

Data Analysis
A repeated measures analysis of variance (ANOVA) (BMDP, Program 2V, Release 7.1, 1993) was used to detect any differences in the FR between groups over the five weeks. Follow-up testing analyzed the simple main effects of group (within group repeated measures ANOVA and Tukey's post hoc test) and week (one-way ANOVA). Significance was set at \( p \leq .05 \).

RESULTS
The mean age of all subjects was 80 ± 5.8 years. Descriptions of age, sex, and initial FR are presented in Table 1. At the outset there were no significant differences between the four groups for age \( F(1,3) = 1.24; p = .223 \) and initial FR \( F(1,3) = 0.60; p = .619 \). Four subjects in the water sitter group who failed to show for any session and nine participants with greater than three absences were excluded from all analysis, leaving 39 subjects. The FRs for the nine participants excluded for absences were: Water exercisers (15.2 cm, 17.8 cm, 25.4 cm); Land exercisers (20.3 cm); Water sitters (15.2 cm, 17.8 cm); Land sitters (27.9 cm, 20.3 cm, 17.8 cm).

The results, as shown in Figure 2, qualitatively demonstrate the FR changes during the 5 weeks in the four different groups. As seen in Figure 2, the FR test of the water exercisers improved a large amount for the first 2 weeks, improved at a slower rate between weeks 2 and 4, and finished with another large improvement between weeks 4 and 5. The land exercisers made their largest gain in the FR test between the start and end of week 1, but only improved slowly, if at all, between weeks 2 and 5. The water and land sitters had only small changes in their FR over 5 weeks.

The results of the overall repeated measures ANOVA showed a significant interaction for groups by weeks \( F(3,15) = 3.07; p = .050 \). Therefore, the simple main effects were analyzed within each group across the 5 weeks with repeated measures ANOVAs. This testing showed significant improvement in the FR test for the water exercisers \( F(1,5) = 21.6; p < .001 \) and land exercisers \( F(1,5) = 3.00; p = .026 \). The water sitters and land sitters did significantly change \( F(1,5) = 2.57; p = .059 \) and \( F(1,5) = 0.47; p = .798 \), respectively over the 5 weeks.

A Tukey post hoc test was then used to determine where differences existed across the weeks within each group (Table 2). For the water exercise group, a significant improvement was found between: the initial measurement and all other weeks; weeks 1 and 4; weeks 1 and 5; weeks 2 and 5; weeks 3 and 5; and weeks 4 and 5. For the land exercise group a significant difference was found only between the initial week and weeks 1 through 5. There was not a significant change found between weeks 1 and 5.

To determine which group improved the most over the 5 weeks of training, a simple main effects analysis across groups at each week was performed. This showed that there was no significant difference between the groups at the end of week 1 \( F(1,3) = 2.72; p = .059 \) and week 2 \( F(1,3) = 2.38; p = .087 \). There was a significant difference at week 3 \( F(1,3) = 5.62; p = .003 \) between groups although no significant contrast between pairs was evident using Tukey's critical values. At weeks 4 and 5 there were significant differences in the FR test \( F(1,3) = 5.62; p = .004 \) and \( F(1,3) = 17.58; p < .001 \), respectively. Tukey's critical values showed that at the end of week 4 the water exercisers reached significantly further than the water sitters and the land sitters, and at week 5 the water exercisers reached significantly further than all other groups. Also, at week 5, the land exercisers reached significantly further than the land sitters.

In addition to their Changes in FR, three water exercisers volunteered that they no longer needed their walkers for community ambulation after 4 weeks of exercise. This change in ambulation status was not reported in any of the other groups.

There were 20 absences in all four groups for the 39 participants (Table 3). In the last 2 weeks of the study there were no change in ambulation status reported in any of the other groups.

Table 1. Initial Description of Experimental Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Initial Reach (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Exercisers</td>
<td>2 M</td>
<td>82.0 ± 5.4</td>
<td>21.6 ± 5.33</td>
</tr>
<tr>
<td></td>
<td>8 F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Exercisers</td>
<td>0 M</td>
<td>78.2 ± 5.8</td>
<td>23.1 ± 2.8</td>
</tr>
<tr>
<td></td>
<td>12 F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Sitters</td>
<td>1 M</td>
<td>77.4 ± 4.9</td>
<td>21.2 ± 3.8</td>
</tr>
<tr>
<td></td>
<td>7 F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Sitters</td>
<td>3 M</td>
<td>81.3 ± 6.5</td>
<td>22.4 ± 2.5</td>
</tr>
<tr>
<td></td>
<td>6 F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Differential changes in functional reach during the 5-week experimental period.
was an increase in absences in the land exercise group which were mostly unexplained; while the water exercisers did not show a change in absences, they had one participant absent per week in the last 3 weeks of the study, and all three absences were mentioned to the examiner prior to the date of absence. The other groups had absences which were without pattern, and were for the most part unexplained.

Follow-up telephone interviews were conducted between 10 and 12 months after the last session, and 19 of the 39 participants were able to be contacted. Through these interviews, information on the additional 20 participants was elicited. Out of all of the participants, at 10–12 months, 80% of the water exercisers were still exercising in the pool. None of the land exercisers continued in an exercise program. Three of the water sitters had joined a water exercise program. All of the card players continued to play cards and did not participate in an exercise program. While this is a small sample, it is also interesting to note that there have been no orthopedic injuries from falls (or other causes) in the water exercise group since the study, while in the land exercise group there has subsequently been one broken hip and one fractured wrist. In the water sitters there has been one fractured hip. In the land sitters there have been two deaths.

**DISCUSSION**

This study was designed to demonstrate if exercise in water is an effective means of decreasing a participant's risk of falling as shown by an increase in their FR. To test this, multiple experimental groups were formed that tested for factors which could also have improved the FR over the 5-week period of water exercise. It is clear in these results (Figure 2, Table 2) that water exercise enhanced these elderly subjects' postural control more than from the benefits of exercise alone; more than from the benefits of water's physical properties; and more than from the benefits of socialization. This is evident in the water exercisers' FR of nearly 35 cm at the end of the 5 weeks and also in their discarding of assistive devices and lack of morbidity and mortality in the year after the study.

Duncan et al. reported that the distance one can reach was directly correlated with their margin of stability (19) and their probability of falling in the coming year (1). The results of the initial testing of the FR (Table 1) demonstrated that the average FR of all participants was within the at-risk range for falls — at least a two times greater risk of falling in the coming year (1). After the first week of exercise, both water exercisers and land exercisers had an average FR of greater than 25 cm and therefore were within the normal risk for falls category. However, by the end of the 5-week study, the water exercisers reached significantly further than the land exercisers.

Not only did the water exercise group reach further than the other groups by the end of the study, but they were more compliant with the exercise program, as seen in their attendance during the last 3 weeks of the study. Furthermore, many of the water exercisers have continued in a water exercise program, whereas none of the land exercisers have continued with exercises. Thus, water exercise may have a longer-term benefit than land-based exercise with the elderly due to better compliance with the water exercise program.

The dramatic improvement in the water exercise group's FR may have been due to an increase in the movement errors they made, detected, and corrected while moving in the water. It is suggested that the exercise in water helped the participants to make and detect errors because the water allowed a larger bandwidth of movement in which the participants could error, receive the feedback that they have erred, and then correct for that error without an increase in their fear of injury.

**Fear of Falling**

Many elderly people may limit their activity due to the fear of possible injury from a fall. This decreased activity may progressively limit functional mobility and social independence (3,24,25). Because of this fear of injury, a traditional land exercise program can be very difficult for an elderly participant to complete without assistance. Water is a dense and viscous medium that rapidly decelerates movement. Because of these physical properties a person is cushioned from injury in the event of a fall, especially when submerged at a level of waist deep or more where at least
50% of his/her weight is supported by the water. As the risk of injury from falling is minimal when exercising in water, the subject's fear of falling should be decreased. It is speculated that by decreasing this fear these elderly subjects were willing to increase the movement magnitude (19,20) and thereby experience greater movement variability and errors.

Variability of Practice

The beneficial effects of the variability of practice have been demonstrated in many studies which have emphasized the need to practice, make errors, and learn from those errors. Thus, making errors guides learning (15,16,26). In the water a participant might be more willing to practice the movements that are needed to prevent a fall and produce movement errors while practicing, as the risk of injury while exercising at waist or chest deep in water was minimal.

Not only may the water exerciser have been more willing to move, but the water may have enhanced movement variability through its unique physical properties. First, the buoyancy provided by the water can be considered destabilizing since it will tend to lift a subject up. Therefore, as a person moves through waist- to chest-deep water where there is a 50-75% decrease in weight bearing, each movement, while similar to movement on land, may be novel. Second, during the water exercise activity, more than one person was moving in the water; this created turbulence which may have increased the variability of the factors influencing each participant's movement.

Both of these factors suggest that the water exercisers' postural control needs continually varied with the constantly changing pool environment. These changing balance requirements would cause the subjects to acquire or enhance their postural control mechanisms in order to prevent a fall.

As shown in Figure 2, the water exerciser's FR improved almost weekly. This suggests that with each week of practice they showed the benefits of continued movement variability. In contrast, the land exerciser's FR improved only during the first week, presumably after which the novelty of the land-based exercise program subsided. This suggests that the land exercise participants experienced the most movement variability in the exercise during the first week of practice. In subsequent weeks the movement errors were minimized as the routine became well learned in the stable environment of the church; hence no improvement was subsequently seen.

While it is posited that the enhancement of the FR in the water exercise group was due to the production of movement errors in the water while exercising, several confounding issues exist. First, all of the participants were from a retirement community whose population consisted of predominantly well educated Caucasians. This group is not representative of elderly population demographics as a whole. In order to have greater external validity, random sampling of elderly subjects across socioeconomic strata would be needed.

Another consideration is that the water sitters did not stand during treatment. Standing would have exposed this group to the same buoyancy and compressive effects as the water exercisers. This group was not asked to stand so as to minimize the continuous postural perturbations which occur while standing in water.

Another consideration is that the water exercise may have provided a more strenuous exercise program than when exercising on land. This effect could be caused by the greater viscosity of water than air. However, the buoyancy provided by the water can assist the movement when the movement is in an upward direction; movement which is against gravity on land. Furthermore, when exercise is completed on the land, physiological lower extremity extension against the earth lifts the full weight of the body, while in water, the weight of the body is partially lifted by the buoyancy provided by the water. Therefore, based on the buoyancy effect arguments, physiological postural extensor muscles may not be strengthened as much as they would be if the exercise was completed on land. Consequently, it is difficult to say that the water exercise group performed the exact same exercise intensity as the land exercise group even though the same exercise movements were completed during the land and the water session.

Finally, the use of only the FR measure when the treatment and data collection were done by the investigator has the potential for experimental bias. While attempts were made to minimize this potential bias, any replication of the results reported herein should attempt to minimize this bias by utilizing multiple measures of balance control as well as blinding the data collection personnel to the participant's group.

In conclusion, this study suggests that the participants of the water exercise program described in this study may have been able to experience a wider range of movement without an increase in the risk of injury due to a fall. Through the use of these movement errors, these elderly subjects were able to enhance their postural control as shown by their increase in FR to an extent that was not seen in any of the other groups.

Acknowledgments

The authors would like to thank Dr. Mark Cornwall and Ms. Karen Mueller for their assistance with preliminary drafts of the manuscript. This research was completed in partial fulfillment of the requirements for Ms. Simmons' MA degree at Northern Arizona University.

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Received June 9, 1995
Accepted February 9, 1996