Gerontology

Gerontology 2006;52:131–141
DOI: 10.1159/000091822

Received: August 8, 2005
Accepted: November 27, 2005

A Five-Week Exercise Program Can Reduce Falls and Improve Obstacle Avoidance in the Elderly

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Key Words
Falls in the elderly · Exercise programs · Postural control · Balance confidence · Obstacle avoidance · Nijmegen Falls Prevention Program

Abstract
Background: Falls in the elderly are a major health problem. Although exercise programs have been shown to reduce the risk of falls, the optimal exercise components, as well as the working mechanisms that underlie the effectiveness of these programs, have not yet been established. ***Objective:*** To test whether the Nijmegen Falls Prevention Program was effective in reducing falls and improving standing balance, balance confidence, and obstacle avoidance performance in community-dwelling elderly people. ***Methods:*** A total of 113 elderly with a history of falls participated in this study (exercise group, n = 79; control group, n = 28; dropouts before randomization, n = 6). Exercise sessions were held twice weekly for 5 weeks. Pre- and post-intervention fall monitoring and quantitative motor control assessments were performed. The outcome measures were the number of falls, standing balance and obstacle avoidance performance, and balance confidence scores. ***Results:*** The number of falls in the exercise group decreased by 46% (incidence rate ratio (IRR) 0.54, 95% confidence interval (CI) 0.36–0.79) compared to the number of falls during the baseline period and by 46% (IRR 0.54, 95% CI 0.34–0.86) compared to the control group. Obstacle avoidance success rates improved significantly more in the exercise group (on average 12%) compared to the control group (on average 6%). Quiet stance and weight-shifting measures did not show significant effects of exercise. The exercise group also had a 6% increase of balance confidence scores. ***Conclusion:*** The Nijmegen Falls Prevention Program was effective in reducing the incidence of falls in otherwise healthy elderly. There was no evidence of improved control of posture as a mechanism underlying this result. In contrast, an obstacle avoidance task indicated that subjects improved their performance. Laboratory obstacle avoidance tests may therefore be better instruments to evaluate future fall prevention studies than posturographic balance assessments.

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0304–324X/06/0523–0131$23.50/0

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Introduction

Falls in the elderly are a major health problem. Approximately 30% of community-dwelling elderly over the age of 65 fall at least once a year and 6% of these falls result in fractures [1, 2]. In the past decade, numerous studies have been conducted to investigate the effectiveness of fall-preventive interventions. Exercise programs or multifaceted programs incorporating exercise training have been used in the majority of these studies. Although not all studies were equally successful in demonstrating the potential benefits of such exercise-based programs in the reduction of fall incidence in the elderly, recent meta-analyses of fall prevention programs have convincingly shown that exercise interventions are effective in reducing the risk of falls and fall injuries [3–5]. However, the content of the optimal exercise program as well as its optimal duration and intensity have not yet been established. Most of the exercise programs that have been investigated were quite demanding to the participants, both with respect to duration, intensity and frequency. This demand resulted in high dropout rates and lack of compliance to the exercise regimen. Secondly, some of those programs that consist of large numbers of supervised exercise sessions may not be cost-effective and, thus, will be less suitable for implementation in daily clinical practice. From these perspectives, the development of a short-term low-intensity program was considered necessary, but the question whether such a program would be equally effective in the reduction of fall risk would still have to be answered.

In the development and evaluation of exercise-based fall prevention programs, there is another issue that deserves attention. It is still largely unknown which working mechanisms underlie the effectiveness of these programs. In previous studies, attempts have been made to answer this question. Many different assessments of balance, gait, muscle strength, and balance confidence have been used to evaluate the effects of the exercise programs in relation to their effects on fall incidence. The results, however, are not as straightforward as might be expected. For instance, in the Atlanta FICSIT trial, a balance-training program based on Tai Chi proved to be successful in reducing fall risk [6, 7]. Sway amplitude, as a measure of postural stability obtained from force-plate posturography, however, did not show significant changes as a result of training. On the other hand, the study of Lord et al. [8] showed significant improvements of total sway path as a result of training, but no overall reduction in fall incidents. These discrepancies suggest that the choice of posturographic parameters may influence the observed results. The question emerges whether other functional tests would provide different information about the effectiveness of various exercise programs. One good candidate for such a test might be an obstacle avoidance task. It has been reported that in the population of community-dwelling elderly over 50% of the falls are due to trips and slips, usually during walking [9]. In many of these cases there is an external, provoking factor, like an obstacle that is tripped over [2]. This fact possibly indicates that a decrease in the number of falls as a result of exercise programs would more likely be associated with improved functional walking skills, such as avoiding obstacles, than with 'static' balance tasks. Previously, an observation based obstacle course has been used to evaluate the effects of an exercise program, but it appeared not sufficiently sensitive to detect subtle changes over time [10]. In contrast, in an obstacle negotiation task with quantitative motion analysis, a number of parameters associated with safe obstacle negotiation improved as a result of strength training [11]. Hence, the benefits of such training could be demonstrated in the laboratory by using a functional walking task. This observation shows the potential usefulness of an obstacle avoidance task in the evaluation of exercise programs aimed at the prevention of falls. No previous studies have been conducted, however, to investigate whether improved performance of obstacle avoidance tasks in a movement laboratory is associated with a decreased fall risk.

The aim of the present study was to evaluate whether a new 5-week exercise program of low intensity, called the Nijmegen Falls Prevention Program, would be effective in the reduction of the number of falls in community-dwelling elderly people. Although this program is of low intensity, its content is rather unique, because balance and coordination are practiced, integrated in an obstacle avoidance course that simulates potential hazardous situations of daily life. These exercises also have to be performed while cognitive and motor dual tasks are imposed, as well as under visual constraints. In addition, the program incorporates exercises to simulate walking in a crowded environment and the practice of fall techniques. In order to gain insight into the potential underlying working mechanisms, posturographic assessments, subjective assessments of balance confidence and objective assessments of obstacle avoidance skills while walking on a treadmill were made before and after the exercise program.

Table 1. Baseline group characteristics

	EX1 group n = 49 (SD)	EX2 group n = 30 (SD)	Control group n = 28 (SD)
Mean age (SD)	73.7 (4.5)	73.2 (6.2)	74.9 (6.5)
Females, %	81.6	76.7	67.9
Mean number of drugs (SD)	1.31 (1.23)	1.20 (1.61)	1.14 (1.58)
Falls			
Fall incidence rate, falls/person-years	1.79*	1.74	1.77
Number (%) of fallers	17 (57)*	18 (60)[a]	9 (32)
Quiet stance			
RMS COP velocity, mm/s (SD)			
Eyes open AP	11.81 (8.62)	10.43 (6.31)	9.78 (3.54)
Eyes open LAT	5.91 (2.74)	5.31 (2.07)	5.74 (2.42)
Eyes closed AP	24.11 (27.70)	18.14 (15.97)	17.29 (9.06)
Eyes closed LAT	9.76 (10.95)	6.56 (4.56)	9.15 (8.48)
Dual task AP	13.36 (8.91)	12.24 (9.47)	11.69 (4.51)
Dual task LAT	5.98 (2.47)	5.08 (2.56)	6.14 (2.91)
Compliant surface eyes open AP	22.15 (10.64)	23.08 (10.43)	22.39 (7.20)
Compliant surface eyes open LAT	12.20 (3.95)	10.32 (3.44)	12.60 (5.70)
Compliant surface eyes closed AP	51.89 (23.85)	50.78 (27.99)	52.91 (16.14)
Compliant surface eyes closed LAT	23.11 (9.31)	20.05 (8.91)	24.05 (9.44)
Weight shifting			
Mean number of weight shifts (SD)			
With visual feedback	11.94 (2.74)	11.77 (2.28)	10.64 (2.77)
Without visual feedback	6.79 (3.44)	6.37 (3.44)	6.43 (3.26)
Timed 1-leg stance (SD)	19.83 (10.04)	21.90 (9.69)	19.50 (10.24)
Balance confidence			
ABC score (SD)[b]	59.44 (17.76)	59.02 (19.66)	60.58 (19.14)
Obstacle avoidance success rates (SD)			
ART 200–250 ms	47.33 (35.65)	57.41 (33.05)	58.40 (36.07)
ART 250–300 ms	69.07 (28.91)	69.63 (27.18)	60.41 (37.18)
ART 300–350 ms	82.69 (18.01)	77.97 (23.28)	70.52 (31.14)
ART >350 ms	94.57 (7.17)	91.97 (13.16)	91.74 (10.23)

SD = Standard deviation; AP = anterior-posterior direction; LAT = lateral direction; ART = available response time.

* n = 30 for baseline fall measures.

[a] Pre-test group difference between EX2 group and control group, $p < 0.05$.

[b] ABC: Activities Specific Balance Confidence, range 0–100, higher scores indicate higher confidence.

Methods

Participants and Study Design

Participants were recruited by means of newspaper advertisements. Participants had to be at least 65 years old and community-dwelling. In addition, they should have experienced at least one fall in the year prior to participation and be able to walk 15 min without the use of a walking aid. The exclusion criteria were severe cardiac, pulmonary or musculoskeletal disorders, pathologies associated to increased fall risk (i.e. stroke or Parkinson's disease), osteoporosis, and the use of psychotropic drugs. These criteria were checked by self-report. Table 1 includes some group characteristics at baseline. All subjects gave informed consent prior to participation. The study was approved by the local Medical Ethics Committee.

Of 183 applications for participation, 70 persons were excluded for various reasons, mostly because they had not experienced a fall or declined participation. Of the 113 participants that were included in the study, the first 49 persons were directly assigned to the exercise program (EX1). Of the other 64 participants, 6 persons dropped out before randomization for medical (n = 2) or social (n = 4) reasons. The remaining 58 participants were randomly assigned to the exercise program (EX2) (n = 30) or to the control group (CON) (n = 28). After randomization, the post-intervention posturographic and obstacle avoidance assessments could not be conducted for 1 participant in the EX2 group due to acute knee com-

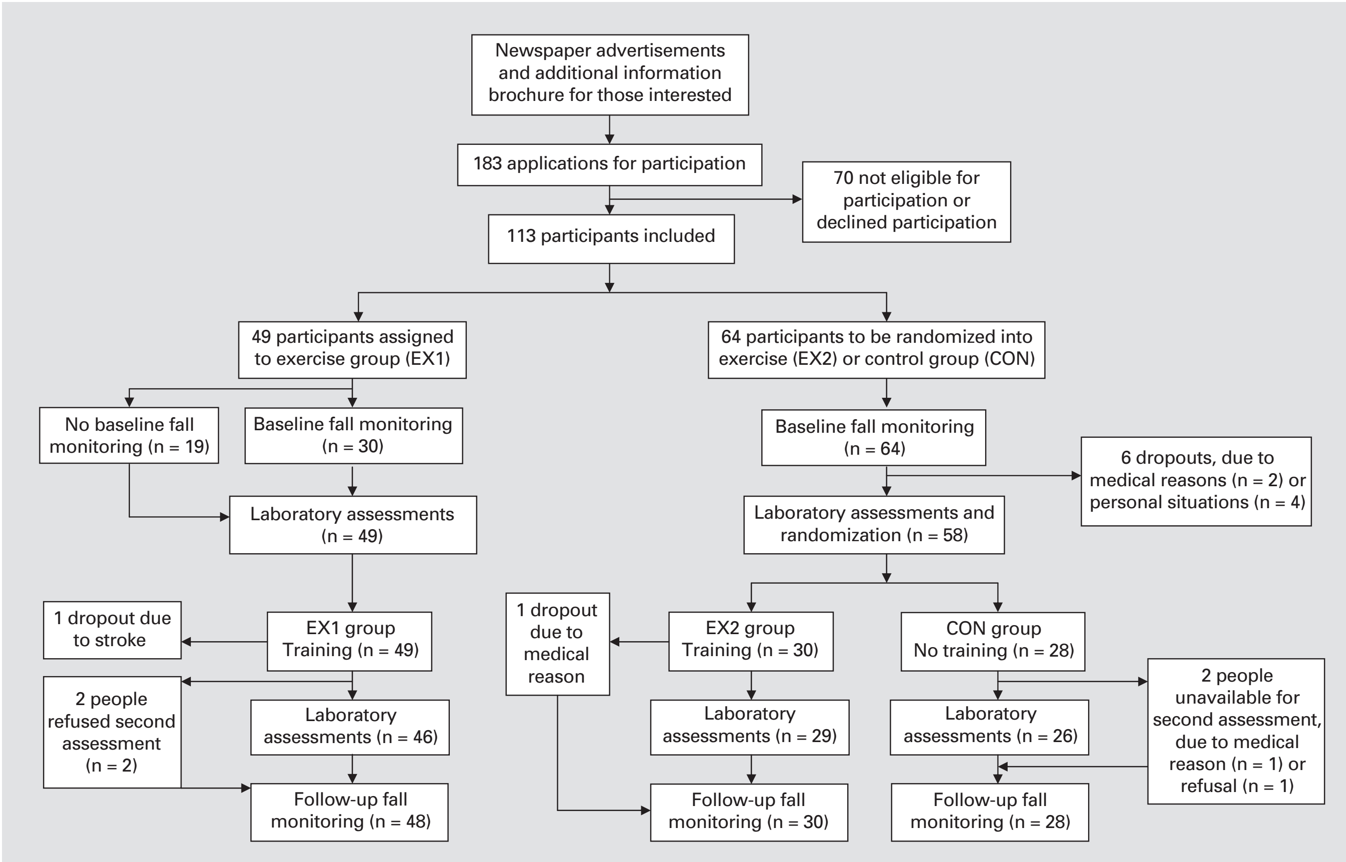

Fig. 1. Flowchart outlining numbers of participants during the study.

plaints (unrelated to the intervention) and for 2 participants in the CON group, 1 person due to intestinal complaints and 1 person refused the assessments. Figure 1 provides a detailed overview of the study's chronology, also of the EX1 group.

Procedure

After inclusion, a median baseline period of 6 months (mean 5.89 months, SD 2.21 months) started during which individual fall incidence was monitored. Thereafter, just before group assignment and randomization, a number of laboratory assessments of balance and obstacle avoidance took place. In addition, all participants received the Activities Specific Balance Confidence Scale (ABC) [12] to be completed at home. Within the following 4 weeks, those subjects assigned to the experimental intervention started the 5-week exercise program. The other (control) subjects did not receive any specific treatment. For all participants, the laboratory assessments and completion of the ABC were repeated within the 4 weeks following the exercise program or within 5–9 weeks from the moment of group assignment. Fall incidence was monitored during a 7-month follow-up period from the moment of group assignment.

Exercise Program

The 5-week exercise program consisted of 10 sessions (2 sessions/week) of 1.5 h each. The first session of the week was dedicated to balance, gait, and coordination training in an obstacle course, which mimics activities of daily life with potential fall risk. Some examples of the elements in the obstacle course are walking over doorsteps, stepping stones, uneven pavement, and over various kinds of ground surface. Reaching from a stool, standing up from a low chair without use of the arms, and making a transfer from stance to a kneeling position were also components of the balance and coordination training. To simulate the complexity of daily life, the balance and gait tasks had to be performed simultaneously with various additional motor and cognitive tasks (25 and 20% of the time, respectively) and under visual constraints (15% of the time). Motor dual tasks were carrying a tray with empty cups, carrying grocery bags or an umbrella. As a concurrent cognitive task, for instance, a story was told that had to be reproduced as well as possible after the participants had finished the obstacle course. A visual constraint was, for example, carrying a tray in front of the abdomen taking away the sight of the feet. During all the exercises, that closely resembled activities of daily life, participants not only practiced difficult situations, but they also learned to recognize and cope with potentially hazardous situations.

The second session of the week consisted of two elements. The first element was formed by a number of walking exercises that simulated walking in a crowded environment with many changes in speed and direction. The second element was based on the practice of fall techniques, derived from martial arts, in forward, backward and lateral directions. The level of difficulty was gradually enhanced by increasing fall height (from sitting on the safety mat to stance height) and time pressure.

Fall Incidence

A fall was defined as an undesired contact of any body part other than the feet with the ground or a lower surface. Falls were monitored monthly using pre-addressed, reply-paid fall registration cards. In addition to the question whether a fall had occurred in the past month, participants were asked to provide a short description of (a) possible fall(s) and of the body part(s) that had hit the ground. This information was used to determine whether each of the reported falls truly met the definition of a fall. Participants were requested to return these cards at the start of a new month. When no fall registration card had been received after 2 weeks, a postcard was sent as a reminder.

Balance Tasks

Balance measurements were made with a dual-plate force platform. Each force plate was placed on 3 force transducers, recording the vertical ground reaction forces at a sample rate of 60 Hz. The position of the center of pressure (COP) was determined for each sample by digital moment-of-force calculations. The coordinates of COP position were low-passed filtered (Fourier filter) with a cut-off frequency of 6 Hz. Root mean square (RMS) values of COP amplitude and velocity were calculated in both anterior-posterior (AP) and lateral (LAT) directions. The RMS COP velocity was selected as the primary measure of postural stability in each direction of body sway, because it has been shown that this measure is more reliable than the RMS COP amplitude [13, 14].

The participants stood barefoot on the force platform with the arms alongside the trunk and the feet against a fixed foot frame (heel-to-heel distance 8.4 cm, 9° external rotation of the feet from the sagittal midline). During quiet standing, they were asked to stand as still as possible on normal and compliant surface (4.5 cm foam), both with eyes open and with eyes closed, and when concurrently performing an arithmetic task (on normal surface only). Each of these quiet stance conditions was repeated 3 times. COP fluctuations during each trial were recorded for 20 s. The first 5 s were always discarded from the analysis to eliminate any undesired starting effects. For each condition, the median RMS value of the 3 trials was included in the statistical analysis for the AP and LAT directions separately.

In addition, a weight-shifting task was included in the posturographic assessment, both with and without visual feedback of the COP [15]. A computer screen was placed 1 m in front of the participant while standing on the platform. A yellow and a blue square (3 × 3 cm) were presented on the screen at 40% of the length of the base of support from the rear. The middle of each square was positioned at 15% of the stance width (i.e. the distance between the anterior borders of both distal tibiae) from the sagittal midline, which corresponded to approximately 65% weight bearing on each corresponding leg to reach the middle of the target. Real-time real-size visual COP feedback was provided by a black cursor on the screen. Participants were asked to move the cursor from one square to the other by means of weight shifts. A successful weight shift was indicated by changing colors of the squares. In the visual feedback condition, the cursor was visible during the whole duration of the recording, which was 45 s. In the no visual feedback condition, the cursor was visible for the first 15 s, after which the weight shifts had to be continued for 30 s without feedback of the COP. One practice trial for each condition was performed and the second trial was recorded. For both conditions, the number of successful weight shifts during the latter 30 s was included in the statistical analysis.

As a clinical balance test, timed one-leg stance was performed with the preferred leg. A maximum of 5 trials was allowed and the best score, with a maximum of 30 s, was included in the statistical analysis.

Balance Confidence

The ABC was selected as a measure of balance confidence. The Dutch version of the ABC was used. Items on which more than half of the participants scored more than 90% of balance confidence at baseline were discarded from the analysis to avoid ceiling effects. The mean score over all remaining items of the ABC was included in the statistical analysis.

Obstacle Avoidance Task

For the obstacle avoidance task, participants walked on a treadmill at a fixed velocity of 3 km/h. This speed was selected, because it falls well within the range of natural walking velocities of both young and older elderly [16]. A bridge was placed over the front of the treadmill, to which an electromagnet was attached. A wooden obstacle (size 40 × 30 × 1.5 cm in length, width, and height, respectively) containing a piece of iron was held by the magnet and could be released by a trigger timed by the computer. The height of the obstacle exceeded only slightly the minimal toe clearance height during unobstructed gait [17, 18], so adaptations of stride length were required in combination with minor vertical adaptations. After release, the obstacle always fell in front of the left foot. Two reflective markers (diameter 3 cm) were attached to the left heel and the hallux. A third marker was placed on top of the obstacle. Marker positions were recorded by a 6-camera 3-D motion analysis system (Primas) at a sample rate of 100 Hz. The whole experiment was recorded on videotape.

Before the experimental procedure was started, the participants had an opportunity to get accustomed to treadmill walking. In addition, 5 practice trials of obstacle avoidance were performed. During the experiment, marker position recordings were real-time processed. Heel strike moment and position were determined and were used to predict the normal landing position. Based on this information the exact moment on which the obstacle had to be dropped was determined by the computer. The obstacle was not released until a regular walking pattern had been achieved, defined as <50 ms difference in stride duration between 2 consecutive strides.

The obstacle was dropped at 1 of 6 different moments during the step cycle, distributed from mid stance to mid swing of the left leg. These moments were chosen to obtain a wide range of resultant available response times (ARTs) [19]. The level of difficulty of obstacle avoidance has been shown to depend on the ART. Mid stance obstacle release corresponded to relatively long ARTs (approx. 450 ms) and easy trials, while mid swing obstacle release corresponded to short ARTs (approx. 200 ms) and, thus, difficult trials. Each step cycle condition was repeated 5 times, randomly distributed across a total of 30 trials (3 series of 10 trials). Participants walked at a fixed position on the treadmill, so that the most anterior position of the toes had a distance of approximately 10 cm to the obstacle prior to its release. Participants were instructed to al-

Table 2. Falls in the exercise and control group

	Baseline	Follow-up	Incidence rate ratio (95% CI)
Exercise group			
Number of falls	55	43	
Observation time, person-years	31.1	45.4	
Fall incidence rate, falls/person-years	1.77	0.95[a]	0.54 (0.36–0.79)
Number (%) of fallers	35 (58)	31 (40)[b]	0.61 (0.38–0.98)
Control group			
Number of falls	21	29	
Observation time, person-years	11.8	16.6	
Fall incidence rate, falls/person-years	1.77	1.75[a]	0.98 (0.56–1.72)
Number (%) of fallers	9 (32)	9 (32)[b]	0.71 (0.28–1.78)

[a] IRR exercise group compared to control group 0.54 (95% CI 0.34–0.86).
[b] IRR exercise group compared to control group 1.26 (95% CI 0.60–2.64).

ways avoid the obstacle. Failures were defined as contact of the foot with the obstacle and were noted during the experiment. In case of doubt, the video recordings were used to judge whether a trial was successful or not. Afterwards, for each trial the resultant ART was calculated (see Weerdesteyn et al. [20]). The ART was defined as the time span between obstacle release and the moment that the hallux would cross the front of the obstacle when no avoidance reaction would occur. Trials were subdivided into ART categories of 200–250, 250–300, 300–350 ms, and >350 ms. For each participant, success rates were calculated for each ART category by dividing the number of successful trials by the total number of trials in that ART category.

Statistical Analysis

First, it was planned to determine whether there were any pretest differences on any of the outcome measures between the groups (EX1, EX2, and CON) by means of one-way ANOVAs, with post-hoc Bonferroni corrections. When no differences would be present between the EX1 and EX2 groups, further analyses could be conducted with the results of these experimental groups combined versus the control group on an intention-to-treat basis.

Fall data were analyzed with respect to total number of falls and the number of fallers (participants with at least one fall). Falls incidence rates (IR) during baseline and follow-up periods were calculated by dividing the total number of falls by the total number of person-years. To compare the fall incidence rates between groups or between periods of time, a fall incidence rate ratio (IRR) was calculated. The same was done to compare the incidence of fallers.

Repeated measures MANOVAs were conducted to compare changes in balance confidence and balance and obstacle avoidance performance, with Time (all analyses), Condition (analysis of quiet stance and weight-shifting) and ART (analysis of obstacle avoidance) as within subject factors and Group as a between-subjects factor. The α levels were 0.05. Post-hoc paired t tests were used to assess which of the conditions or ART categories showed significant differences. α levels of 0.05 were corrected for the number of post-hoc tests per analysis per group.

Results

Baseline Group Characteristics and Exercise Sessions Attendance

The three groups were comparable with respect to age, gender, drug use, posturographic assessment, timed one-leg stance, balance confidence scores and obstacle avoidance performance at baseline (see table 1). Despite randomization, the proportion of fallers in the control group was significantly smaller than in the EX2 group ($p = 0.034$), but fall incidence rates showed no differences between the groups. There was no baseline group difference in falls monitoring time, so this could not explain the smaller proportion of fallers in the CON group. There were no significant differences between the EX1 and the EX2 group for either the proportion of fallers or the fall incidence rate. Hence, in the statistical analyses the results of both exercise groups were combined. The mean attendance rate to the exercise sessions was 87% for both groups. Of all participants, 51% attended the maximum number of 10 sessions.

Falls

During the baseline period, there was 1 participant with 12 falls in the exercise group and 1 subject with 8 falls in the control group. To avoid overweighting of these participants, only the first 6 falls per person per period were included in the analyses of the total numbers of falls. The calculated fall incidences are presented in table 2. In the exercise group, the falls IR decreased from 1.77 falls per person-year during the baseline period to 0.95 falls per person-year during the follow-up period (falls IRR

Table 3. Mean values (SDs) for pre- and post-test balance and balance confidence measures

	Pre-test	Post-test
Exercise group (n = 75)		
Quiet stance		
RMS COP velocity, mm/s		
Eyes open AP	11.48 (7.97)	12.29 (8.45)
Eyes open LAT	5.74 (2.56)	5.78 (2.60)
Eyes closed AP	22.35 (24.52)	20.93 (18.88)
Eyes closed LAT	8.68 (9.38)	7.99 (4.69)
Dual task AP	13.06 (9.29)	14.64 (13.86)
Dual task LAT	5.69 (2.57)	6.00 (3.11)
Compliant surface eyes open AP	22.74 (10.70)	24.27 (13.91)
Compliant surface eyes open LAT	11.50 (3.93)	11.74 (5.03)
Compliant surface eyes closed AP	52.10 (25.73)	54.09 (29.80)
Compliant surface eyes closed LAT	22.23 (9.36)	22.84 (11.19)
Weight shifting		
Number of weight shifts		
With visual feedback	11.76 (2.56)	12.65 (2.30)**
Without visual feedback	6.82 (3.38)	7.85 (3.72)*
Timed 1-leg stance, s	20.75 (9.75)	23.29 (9.56)**
Balance confidence		
ABC score[a]	59.88 (18.6)	63.38 (17.38)**
Control group (n = 26)		
Quiet stance		
RMS COP velocity, mm/s		
Eyes open AP	9.60 (3.36)	10.72 (3.14)**
Eyes open LAT	5.69 (2.49)	6.45 (2.85)
Eyes closed AP	17.13 (9.39)	18.16 (13.44)
Eyes closed LAT	9.11 (8.81)	8.38 (6.17)
Dual task AP	11.43 (4.58)	12.45 (7.32)
Dual task LAT	6.03 (2.99)	5.72 (2.83)
Compliant surface eyes open AP	22.42 (7.39)	22.10 (6.07)
Compliant surface eyes open LAT	12.65 (5.92)	10.99 (3.89)
Compliant surface eyes closed AP	51.80 (16.05)	44.36 (10.38)**
Compliant surface eyes closed LAT	24.21 (9.77)	20.23 (8.35)
Weight shifting		
Number of weight shifts		
With visual feedback	10.69 (2.85)	12.31 (2.29)***
Without visual feedback	6.69 (3.12)	6.50 (3.33)
Timed 1-leg stance, s	19.54 (10.18)	22.62 (9.41)*
Balance confidence		
ABC score[a]	59.92 (20.30)	58.44 (23.72)

AP = Anterior-posterior direction; LAT = lateral direction.
Post-hoc comparisons with pre-test: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
[a] ABC: Activities Specific Balance Confidence, range 0–100, higher scores indicate higher confidence.

0.54, 95% CI 0.36–0.79). In the control group, the falls IR was 1.77 falls per person-year during the baseline period and 1.75 falls per person-year during the follow-up period (falls IRR 0.98, 95% CI 0.56–1.72). Comparing the follow-up falls IR between the exercise group and the control group, the falls IRR was 0.54 (95% CI 0.34–0.86).

The proportion of fallers in the exercise group decreased from 58% during the baseline period to 40% during the follow-up period (fallers IRR 0.61, 95% CI 0.38–0.98), whereas the proportion of fallers in the control group (32%) did not change. Because the proportion of fallers in the exercise group was larger than in the control group

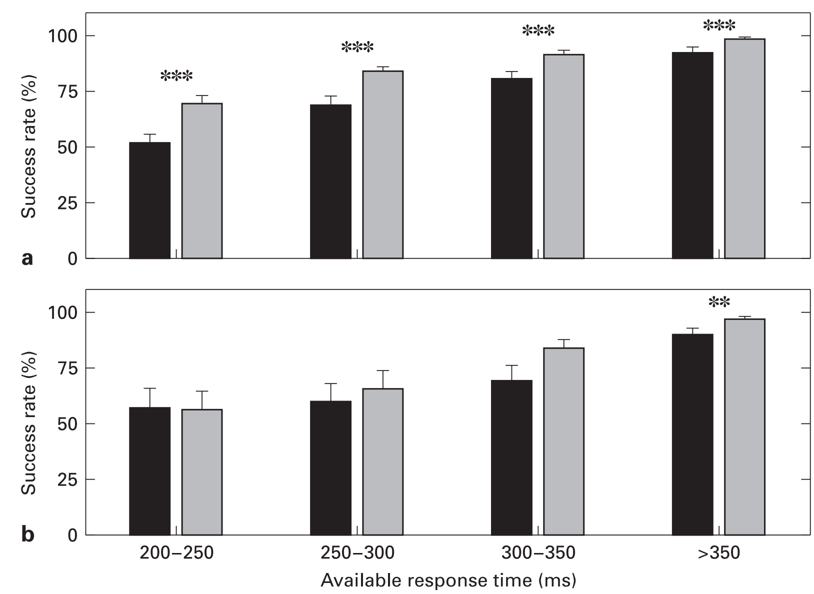

Fig. 2. Mean obstacle avoidance success rates and standard errors of exercise (**a**) and control group (**b**) for the four categories of available response time. Pre-test values are shown in black, post-test values in grey. The asterisks indicate significant differences with pre-test. ** p < 0.01, *** p < 0.001.

during the baseline period, this reduction in the proportion of fallers did not result in a significant difference between exercise and control group during the follow-up period.

Balance Tasks

Pre- and post-intervention balance data were available for 101 participants. Table 3 shows means and SDs of balance and balance confidence measures for the exercise and the control group. In this table, only the RMS COP velocities are presented but RMS COP amplitudes showed a similar pattern of results and significance. Analysis of the RMS COP velocities during quiet stance revealed a significant Time × Group interaction ($F(1,95) = 4.424$, $p = 0.038$), but no significant main effect of Time ($F(1,95) = 0.404$, $p = 0.527$). Post-hoc analyses showed that the exercise group showed no significant difference between pre- and post-intervention assessments, whereas the control group showed a 12% increase in the RMS COP velocity in the anterior-posterior direction while standing on the normal surface with eyes open condition as well as a 14% decrease in the RMS COP velocity in this direction while standing on the compliant surface with eyes closed. Analysis of the number of weight shifts yielded a significant main effect of Time ($F(1,98) = 13.623$, $p < 0.001$), but no significant Time × Group interaction ($F(1,98) = 0.300$, $p = 0.585$). The exercise group improved 8–15% on both weight-shifting tasks, whereas the control group only improved the number of weight shifts made with visual feedback by 15%. Analysis of timed one-leg stance yielded a main effect of Time ($F(1,99) = 14.336$, $p < 0.001$), but no Time × Group interaction ($F(1,99) = 0.127$, $p = 0.722$) (see table 3). Post-hoc analyses showed that both exercise and control groups showed 12–16% improvement at the second assessment.

Balance Confidence

Six participants did not complete the ABC questionnaire correctly or did not return it, so that pre- and post-intervention ABC scores were available for 95 participants. Seven items were deleted based on baseline assessment. Analysis of balance confidence scores revealed a significant Time × Group interaction ($F(1,93) = 4.18$, $p = 0.044$). At the end of the program, balance confidence had improved by 6% in the exercise groups, whereas the control group showed an insignificant (2%) deterioration across time (see table 3).

Obstacle Avoidance Task

Six participants were not capable of performing the obstacle avoidance task, so that obstacle avoidance data were available for 95 participants. Obstacle avoidance success rates are shown in figure 2. There was a significant main effect of Time on obstacle avoidance success rates

($F(1,86) = 46.48$, $p < 0.001$), which indicated that both exercise and control groups showed improved obstacle avoidance performance 5–9 weeks after group assignment. However, a significant Time × Group interaction ($F(1,86) = 5.39$, $p = 0.023$) indicated that the exercise group showed larger improvements of obstacle avoidance success rates (on average 12%) than the control group (on average 6%) and a significant Time × ART × Group interaction ($F(3,84) = 3.52$, $p = 0.018$) indicated that this difference was dependent on ART. Post-hoc analysis showed that the larger improvement in the exercise group as compared to the control group could be attributed to the trials of the short (<350 ms) ART categories.

Discussion

In the present study, the effects of a 5-week, low-intensity exercise program on falls, standing balance, balance confidence, and obstacle avoidance performance were investigated. One of the reasons to aim for a short-term and low-intensity program was to have optimal compliance to the exercise regimen. Both the high attendance rate (87%) and the small number of dropouts during the training period indicate nearly maximal compliance. Although the duration was short and the intensity low, the program resulted in a, clinically meaningful, 46% reduction in the number of falls. Based on this result, the Nijmegen Falls Prevention Program could make a useful addition to the previously reported effective interventions [6, 7, 21–23].

A limitation of this study was that no randomization procedure was applied to the participants in the EX1 group. The participants' characteristics in the randomized (EX2) and non-randomized (EX1) exercise groups, however, were very similar. There were no significant differences between these groups at baseline, so no differential effects of the exercise program would be expected in the groups. This was confirmed by the finding that the exercise program had a similar effect on the number of falls in both groups, with a reduction in the number of falls of 45 and 49% in the EX1 and EX2 group, respectively. Although evidence for the effectiveness of the program would have been more conclusive in a fully randomized clinical trial, it is unlikely that the direct assignment of the EX1 group to the exercise program has biased the final outcome of this study towards a more positive outcome.

One of the novelties of the Nijmegen Falls Prevention Program that may explain the good outcome of this study is the type of the exercises. In many studies, balance, gait, and coordination have been practiced using isolated exercises. In contrast, in this study these physical qualities were practiced in an exercise environment that simulated complex situations of everyday life. In this way, participants also learned to recognize potentially hazardous situations and adopt strategies to minimize the risk of falling. Hence, the fall-preventive effect of the Nijmegen Falls Prevention Program may not only rely on physical training effects, but also on cognitive and behavioral changes. Indeed, the potential benefits of falls prevention programs targeted at both physical and cognitive-behavioral changes have recently been shown by Clemson et al. [24]. They observed a 31% reduction in falls as a result of such an intervention. The results of the present study are in accordance with Clemson's study [24], but in addition, it was possible to show that the intervention resulted in functional changes related to the skills of obstacle negotiation.

The ability to avoid obstacles successfully is an important skill that is necessary for safe locomotion over uneven terrain. The frequent reports of obstacle related falls indicate that a deterioration of this skill could contribute to the high fall incidence in the elderly. For this reason, obstacle negotiation, integrated in a functional obstacle course, has been implemented in the Nijmegen Falls Prevention Program. The results of the applied obstacle avoidance task showed that the exercise group substantially improved avoidance success rates, and that the improvements were larger than in the control group at the shorter ARTs (200–350 ms). It has been shown that the initial timing of obstacle avoidance reactions is very fast (on average 122 ms [25, 26]), which limits the possible contribution of cognitive control to the initiation of such gait adjustments. Because there is evidence that the effects of exercise training are more likely to be found in the spatial avoidance characteristics (e.g. foot-obstacle clearance [11]), which are known to be accessible by cognitive processes [27], improved cognitive control of gait (especially under time pressure) may underlie the reduced incidence of falls as a result of the applied training program.

Furthermore, the results of the present study show that functionally important effects of training on obstacle avoidance skills could be demonstrated by means of a laboratory obstacle avoidance task. In a previous study [11], such a task also proved to be useful as an evaluation tool for a strength training program for the elderly. On the basis of these results, it can be recommended to consider the application of these laboratory tasks as evaluation tools in future training studies.

In the present study, posturographic assessments of quiet stance and weight-shifting were performed as well, because functional balance training was another important aspect of the Nijmegen Falls Prevention Program. However, these instrumented assessments did not provide clear evidence of improved automatic or voluntary control of posture. Still, the exercise group demonstrated a small improvement in balance confidence, which may have been influenced by an expectation effect. Taken together, a decreased numbers of falls, increased balance confidence, but a lack of training effects on basic control mechanisms of standing balance are in accordance with the results of Wolf et al. [7]. Quiet stance posturography has been designed to evaluate basic equilibrium reactions. Compared to reference values obtained from healthy elderly without a history of falls [28], the participants in the present study demonstrated RMS COP velocities well outside the normal confidence limits, which is indicative of impaired equilibrium reactions. Hence, the absence of training effects on these balance tasks cannot be explained by floor effects. An explanation for the observed lack of improvement is that the automatic equilibrium reactions responsible for the control of quiet standing are not responsive to exercise training. Previous training studies have yielded conflicting results with regard to this issue [7, 8, 23, 29–32]. Although there is no final answer to this question yet, quiet stance assessment may not be the most suitable evaluation method to determine the effects of falls prevention exercise programs in community-dwelling elderly. In anticipation of this, in the present study, two weight-shifting tasks have been added to the posturographic task set. However, both the exercise and the control groups showed significant increases in the number of weight shifts without clear differential effects. Recently, dynamic balance tasks have been used to evaluate the effects of a computerized balance training program for institutionalized elderly women [33]. The exercise group showed larger improvements on dynamic balance than the control group. Yet, these results may have been due to test-specific learning, as training and testing conditions were quite similar. Hence, it is still unclear whether dynamic balance tasks really have additional value to the usually applied static balance assessments in the evaluation of exercise programs.

In conclusion, the present study provides a clear indication that the Nijmegen Falls Prevention Program was effective in reducing the incidence of falls in otherwise healthy elderly. Force-platform posturography did not provide evidence of improved automatic or voluntary control of posture as mechanisms underlying this result. In contrast, an instrumented obstacle avoidance task indicated that subjects improved their performance, which may be explained by improved cognitive control of stepping. Laboratory obstacle avoidance tests may, therefore, be better instruments to evaluate future fall prevention studies than posturographic balance assessments. Our next step is to determine precisely which characteristics of obstacle avoidance contributed to the improved success rates.

Acknowledgments

The authors would like to thank Willem Hellebrand, Bart Engelen, and Inger Sierevelt for their assistance in the development of the program. This study was supported by the Organization for Healthcare Research in the Netherlands (ZonMW) and a EU grant (Eurokinesis, No. QLK6-CT-2002-00151).

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