Motor plasticity in a juggling task in older adults—a developmental study

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Abstract

Objective: to examine the plasticity of motor performance in old age. Older adults were instructed and trained in a juggling task and their performances were compared, first, within the group of older adults and, second, with the performances of children, youths and younger adults.

Subjects: older adults, children, youths and younger adults (n = 1,206, range 6–89 years).

Methods: participants were asked to learn a juggling task. Performance was tested before semantic instruction (pre-test 1), after semantic instruction (pre-test 2) and after 6 days of juggling practice (post-test). None of the participants had prior experiences in juggling. Results were analysed using repeated measure analysis of variance (ANOVA).

Results: older adults showed a clear improvement in juggling performance after instruction and after six training sessions. On average, they reached performances comparable with those of children aged between 10 and 14 years, and with those of younger adults aged between 30 and 59 years. Only youths and younger adults aged between 15 and 29 years showed significantly higher performances at baseline, after instruction and after training.

Conclusions: older adults exhibit high reserve capacity, that is, a potential for learning ‘new’ motor skills.

Keywords: ageing, human development, practice, learning, motor skills, elderly

Introduction

Physical function is central to most of our activities. Our physical efficiency permeates all aspects of our life, and it becomes a constraining factor in what we can do, and in turn it can define our quality of life. There is broad evidence that a physically active lifestyle is associated with improvements in functional abilities and health status and that it may prevent certain diseases or diminish their severity [1, 2]. Consequently, the World Health Organization defines active ageing as one important factor to optimise health and to enhance quality of life, and it promotes physically active lifestyles in older adults [3, 4].

Previous research has shown the age-related impairments of and the benefits of physical activity on motor functions [5, 6]. Many of these articles on healthy older adults...
focus on muscle strength, endurance and balance [7–9]. Thus, effects of strength, endurance and balance training on healthy older adults are well documented [7, 10–14]. Results indicate that much of the reduction in motor performance and physical fitness and the low functional level associated with ageing may be due to inappropriate (sedentary) lifestyle leading to loss of muscle strength, endurance and balance rather than to ageing itself.

The effects of age-related decrements in performance levels, practice gains and "new" learning are also well known for a variety of working skills and fine motor tasks [15–17]. However, only few studies investigated the learning performance of gross motor skills in older age [18–21]. As of yet, there are no precise assumptions to how advanced the trainability of gross motor skills is related to advancing age and whether it is a changing function over the entire lifespan. Because of the lack of research on motor plasticity of gross motor skills in older adults, the objective of the present study was to investigate the amount of motor plasticity in older adults (over 60 years of age).

With respect to cognitive ageing research on plasticity [22–24], we investigated the learning gains due to instructions and practice. Specifically, we investigated motor plasticity in motor skill learning using a juggling task. Typically, people have no earlier experiences in juggling. Thus, the emphasis of this study was on "new" learning and not on maintenance or improvement of motor skills acquired in the past. Our first interest was in the development of juggling performance within the group of older adults at three times of the learning process. Following previous cognitive research [23, 24], we investigated the extent to which the performance before semantic instruction (pre-test 1), after semantic instruction (pre-test 2) and the potential to further refine a complex motor task by training (post-test) is preserved in older adults. In line with previous motor and cognitive research, we assumed that older adults would show a sizable level of juggling performance following training. Furthermore, we expected age-related differences in performance level within the group of older adults. Gender effects were not expected. Our second objective was to compare the older adults’ performances with the performances of children, youths and younger adults. This comparison seems to be necessary to obtain an estimate of the size of age-related reductions in plasticity. As compared to younger adults and youths, older adults’ performance and motor plasticity would be assumed to be lower.

**Method**

**Subjects**

The motor plasticity study in older adults was part of a large multivariate study on lifespan differences in motor performance (MODALIS) [25]. The original sample size of the study was \( n = 1,206 \), including ages from 6 to 89 years (602 men and 604 women). Two hundred and seventy-eight adults were between ages 60 and 89 years. All adults participated voluntarily in the study; they were solicited through advertisements and during their stay in a health centre. Participants provided informed consent to the procedures of the study approved by the University of Bielefeld, Germany, Review Board and participated without pay. Participants had medical clearance and were screened for health restrictions before recruiting by a trained interviewer. Participants were excluded from the study if they had a history of cardiovascular diseases or any motor or cognitive restriction. The children and youths were examined at school (elementary and high school) during their regular physical education lessons by trained experimenters. Children’s parents were informed about the study and confirmed study participation for their children. No child had to be excluded due to cognitive or motor learning disabilities.

All participants were given a demographic and health questionnaire, supplemented by personal interviews, and a battery of motor tests. A standard cognitive test was not used. Expected age-related decrements in advancing age were shown for the motor ability status (e.g. balance, reaction time) but not for the physical activity level (cf. Table 1). Participants who were absent for more than one test day or training session and participants who had earlier experience or training in juggling were excluded. The remaining group consisted of 917 participants. For data analysis, participants were divided into age groups in 5-year intervals (cf. Table 1). Owing to the low sample size, participants between 80 and

Table 1. Sample size (\( n \)), separated for females (F) and males (M) physical activity level and results of motor ability tests

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The 1,206 participants were divided into age groups in 5-year intervals. Results (\( z \)-scores) of selected motor ability tests (reaction time RT), motor balance B and physical activity levels (PA, percentage of participants who were not physically active) within the age groups. A battery of motor tests was used to assess the motor status of the participants. Reaction time was assessed using a stick-fall test [32, 33]. Participants were asked to grip a falling stick as soon as possible with their dominant and non-dominant hand (distance in centimetres was measured). Motor balance was measured by walking backwards on three balance beams with widths of 6 cm, 4.5 cm, and 3 cm [34]. The number of steps on each beam was counted and a sum score calculated. For data analysis, raw scores were \( z \)-transformed across the whole sample. Physical activity level was assessed by a physical activity questionnaire asking for the number and frequency of all actual sport and leisure time physical activities. The percentage of active/non-active participants within the age groups was calculated.
Task, procedure, test sessions and training

Task

Participants were asked to learn two kinds of juggling: first, juggling with three scarves (50 × 50 cm for adults, 40 × 40 cm for children) and, after that, juggling with three balls (diameter of 6.5 cm and weight of 120 g for adults, diameter of 5 cm and weight of 80 g for children). The selection of the juggling skill was based on detailed criteria and preliminary investigations. For example, the motor skill needed to be (i) capable of being learned across the lifespan and within a reasonably short period of time; (ii) novel, that is, no previous experience was required to complete the exercise; (iii) largely independent of physical abilities (endurance, strength and flexibility) and highly motivating. In pilot studies, analysis had shown that the motor skill juggling was particularly suitable, met all criteria mentioned above and was characterised by high reliability (Cronbach's Alpha ranged between $\alpha = 0.94$ at pre-test 1 and $\alpha = 0.97$ at post-test).

Procedure and test sessions

The training programme comprised a total of eight sessions. At the first session (pre-tests 1 and 2) juggling performance was assessed (Monday). Baseline performance (pre-test 1) was assessed by demonstrating the task to the participants (five cascades), but none of the participants got a precise description of the skill to be learned at this stage. Between pre-tests 1 and 2, participants were semantically instructed in juggling by demonstrating the motor skill and by pointing out characteristics of movements, but without any physical practice. The next six sessions (sessions 2–7) were practice sessions (Tuesday to Friday and following Monday to Tuesday) in which participants systematically learned and practiced the juggling task. Practice effects were assessed at session 8 (post-test) (Wednesday). At each test session in pre- and post-test, participants were given five test trials. A video camera was used to record the juggling performance of the participants. Two trained experimenters analysed the juggling performance independently by watching the slow motion videotapes. The experimenters were blinded to the age of the participants as far as possible. They used a detailed quantitative scale to score the juggling performance with scarves and balls. Scoring differences were decided after discussion. Every thrown and caught scarf and ball was counted. The maximum range for juggling with scarves was five cascades (45 points); the maximum range for ball juggling was 10 cascades (90 points), with a cascade consisting of a complete circle of the three objects (9 points). For data analysis, the means of the best three of five trials of juggling with scarves and juggling with balls were summed overall.

Training

In the six training sessions (15 min each), first, each participant learned juggling with scarves (five cascades without an error), then he or she was allowed to start with the ball-juggling task. For both skills, we used the same 17-step course of instructions [26]. The course of instruction started with juggling of one scarf (e.g. ‘Throw one scarf with your right hand and catch it with your left hand.’) and continuously increased difficulty up to three scarves. Participants were asked to practice each step five times without an error. After a participant had completed the 17-step course of instruction with scarves, he or she started the same course again with balls. Thus, training was individualised with regard to the learning achievements of each participant and standardised over the time (6 × 15 min), the instructions and the issues.

Statistical analysis

To investigate the effects of training, age and gender within the sample of the older adults (60–79 years), a repeated measure analysis of variance (ANOVA) was computed with test session (pre-test 1, pre-test 2 and post-test) as the within-subject variable and with age group (60–64, 65–69, 70–74 and 75–79 years) and gender as the between-subject variables. Greenhouse Geyser adjustment is reported when the sphericity assumption was violated. Post hoc contrasts (Bonferroni adjustment) were used to determine effects within the age groups and to determine differences between the times of assessment.

In a next step, the juggling performances of the older adults were compared with the results of children, youths and younger adults using a 3 (time of assessment) × 12 (age groups) mixed factor ANOVA with repeated measures on the first factor and corresponding post hoc tests. Owing to the unequal group sizes (cf. Table 1) and a violation of homogeneity, a stringent alpha level was used ($\alpha = 0.01$) [27]. Due to the low number of men and women, respectively, within the age group 25–29 and 30–34 years, gender effects across the lifespan were not analysed.

Results

Effects of instruction and practice in older adults

The juggling performances across the lifespan are given in Figure 1. The right side of the figure is separated by a dashed line and marks the results of older adults (60–80+ years) (cf. also Table 2 for M and SD and results separated by gender). ANOVA for the groups of older adults (60–64, 65–69, 70–74, 75–79 years) revealed a significant difference between the time of assessment [$F(1.83, 343.17) = 1,440.33, P<0.01, \eta^2 = 0.89$] but no significant effect of age [$F(3, 188) = 0.19, P = 0.91$] and gender [$F(1, 188) = 2.50, P = 0.12$] and no significant time × age interaction [$F(5.48, 343.17) = 1.20, P = 0.31$]. Younger old adults did not perform on a significantly higher level as compared with older old adults. Time by gender interaction, however, was significant [$F(1.83, 343.17) = 5.62, P<0.01, \eta^2 = 0.03$]. Whereas men show higher performance improvements from pre-test 1 to pre-test 2, women improved their performance from pre-test 2 to post-test to a higher degree (cf. Table 2). Time of assessment by age by gender interaction was not significant [$F(5.48, 343.17) = 1.84, P = 0.10$].
As expected, post hoc contrasts confirmed that performance after instruction (pre-test 2) was significantly higher than performance at baseline (pre-test 1) and that performance after practice (post-test) was significantly higher than performance after instruction (pre-test 2) (always \( P < 0.01 \)). On average, older adults between 60 and 79 years learned to juggle five cascades with scarves plus one cascade ball-juggling (cf. Figure 1). As shown in Figure 1, only the very old adults (80+ years) experienced—descriptively—clear diminished juggling performance.

Four participants (all in age group 70–74 years) did not learn to juggle with three scarves. Their performances ranged between less than one cascade (\( n = 3 \)) and less than three cascades (\( n = 1 \)). Consequently, Table 2 indicates the high variability within this age group. Also in the age group 80+, two participants reached less than one cascade scarf juggling. However, nearly 80% of the participants learned to juggle with scarves plus first trials in ball juggling (cf. Table 2 for M and SD). They reached performance levels comparable with the mean performance levels of the other age groups (60–64 to 75–79 years) of older adults.

### Comparison of older and younger participants

Owing to the lack of age effects for older adults, the four age groups of older adults were classified into one group (60–79 years). The \( 3 \times 12 \) mixed factor ANOVA showed a significant effect of time of assessment \([\text{F} (1.55, 1,384.39) = 1,643.46, P < 0.01, \eta^2 = 0.65]\), a significant age effect \([\text{F} (11,894) = 56.84, P < 0.01, \eta^2 = 0.41]\) and a significant time by age interaction \([\text{F} (17.03, 1,384.39) = 17.75, P < 0.01, \eta^2 = 0.18]\). Juggling performance increased significantly with instruction and training, whereby the shape of the learning function was different across the age groups. Post hoc contrasts indicated that older adults (60–79 years) performed significantly higher than the age group 5–9 years and significantly lower than 15- to 29-year-old youths and younger adults (always \( P < 0.01 \)).
The computation of post hoc contrasts separated by test session indicated significantly higher performances of older adults as compared with 5- to 9-year-old children for pre-test 2 and post-test performance ($P<0.01$) but not for pre-test 1 performance. Furthermore, older adults’ baseline performance, performance after the short instruction phase and performance after six training sessions were significantly lower as compared with the ages of 15–29 years (pre-tests 1 and 2) and 15–24 years (post-test), respectively (always $P<0.01$). Older adults’ performances were comparable with the performances of 10- to 14-year-old children and adults between 25–30 and 59 years.

**Discussion**

The purpose of this study was, first, to describe motor plasticity for ‘new learning’ of a complex motor skill in older adults and, second, to compare older adults’ performances with the motor plasticity of younger adults, children and youths. The main findings of this study are as follows: (i) older adults show a high potential to acquire and further refine the complex motor task juggling; (ii) no statistically significant decrease in motor plasticity between the ages of 60 and 79 years can be observed and (iii) older adults’ performance is comparable with the performance of children in the age group 10–14 years and of adults between 25–30 and 59 years. Only youths and young adults (between 15 and 24–29 years) perform on a higher level and show a peak in performance (cf. Figure 1).

Older adults produce large improvements in juggling performance—with certain limitations beginning at the age of 70 years—and demonstrate a substantial motor plasticity for new motor skills. Particularly, the benefits for motor skill learning accrue after a relatively short period of time, namely after six 15 min practice sessions. This is valid for women and men.

The current results are in line with other motor studies that have shown learning and improving sport motor skills in older age is still possible [19, 20]. Several cognitive studies, however, have shown that younger adults benefit more from the training programmes than older adults (i.e. memory training) [23, 24, 28]. These results are interpreted as a substantial age-related reduction in cognitive plasticity. Our results might indicate that older adults are able to activate reserve capacities, compensate for motor and cognitive weakness and in turn show learning gains comparable to younger adults. However, although older adults show comparable performance gains, their absolute performances in pre-test 1, pre-test 2 and post-test are on a lower level than the performances of young adults between 15 and 29 years. Although all participants were naïve to the task in pre-test, younger adults were much quicker to pick up the task in pre-tests 1 and 2 at once just by observation and explanation, respectively, resulting in higher pre-test performance levels.

One might assume that the high physical activity level of the older adults might positively influence their motor plasticity. We did not find, however, a significant correlation between the physical activity level and performance in juggling task (always $P>0.05$).

The lifespan perspective makes it possible to obtain an estimate of the size of age-related reductions in plasticity, and it underlines the high amount of motor plasticity in older age. A typical comparison of younger (mostly students) versus older adults—as done in most cognitive and motor studies [e.g. 23]—would have underestimated the performances of the older adults. Our results indicate that the reduction in motor plasticity occurred not particularly in older age but more in young and middle age (after a peak in youth and younger adulthood).

This study has several limitations. At this point of research, we are not able to make statements regarding motor skill learning in general and its development across the lifespan, because skill acquisition is highly specific and in addition there might generally be little or no transfer of training from one motor skill to another [29]. The high plasticity in motor skill learning of juggling is one example for ‘successful ageing’, however. The results suggest that older adults are still able to react to changing circumstances and to handle new situations with the development of new behavioural patterns. Further studies that examine motor performance and motor learning in tasks, that show a stronger connection to activities of daily living, are required and will provide broader insight into the potentials of older adults. Second, we did not integrate a retention task. Thus, we do not know if older adults lose the performance gains (in the less automatized aspects of the juggling tasks) more quickly than middle-aged and young adults, as shown in other studies for perceptual [30] and non-perceptual motor skills [31]. Third, the present results describe the development of motor plasticity of a gross motor skill that relies on eye–hand coordination across the lifespan. Our data do not allow us to make causal explanations. Additional work is needed that focuses on the reasons for age-related differences, for example, on how neurophysiological changes affect motor skill learning performance.

**Key points**

- Instruction and practice in a juggling task lead to considerable performance improvements in healthy older adults.
- Older adults do not benefit significantly less from the training programme than older children (10–14 years) and younger adults (30–59 years).
- Only youth and younger adults between 15 and 29 years perform on a clearly higher level as compared with older adults.
- Normal ageing is not necessarily associated with a strong reduction or even a complete loss of the ability to acquire and improve a motor skill (motor plasticity).

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**Conflict of interest declaration**

There are no conflicts of interests.

**References**


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