Practice-Related Improvements in Postural Control During Rapid Arm Movement in Older Adults: A Preliminary Study

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Background. Postural control associated with self-paced movement is critical for balance in older adults. The present study aimed to investigate the effects of a virtual reality–based program on the postural control associated with rapid arm movement in this population.

Methods. From an upright standing position, participants performed rapid arm–raising movements toward a target. Practice-related changes were assessed by pre- and posttest comparisons of hand kinematics and center of pressure displacement parameters measured in a training group (mean age: 71.50 ± 2.67 years, $n = 8$) and a control group (mean age: 72.87 ± 3.09 years, $n = 8$). Training group participants took part in six sessions (35–40 minutes per session, three sessions per week). During the two test sessions, arm raising was analyzed under two conditions of stimuli: choice reaction time and simple reaction time.

Results. We observed improvements in the arm movement after training under both conditions of stimuli. The initial phase of the center of pressure displacement, especially the anticipatory postural adjustments, was improved in the choice reaction time condition.

Conclusions. Our short training program resulted in motor optimization of the postural control associated with rapid arm movements, and this implies central changes in motor programming.

Key Words: Older adults—Practice—Anticipatory postural adjustment—Motor program—Learning—Rehabilitation.

HUMAN balance is based on complex mechanisms involving several sensory systems such as proprioception, vision, vestibular information, and muscular function. Several studies have tried to define system-specific age-related declines as a means of preventing falls in older adults (1–4). Instead of investigating the peripheral causes of falls, some researchers suggest that integration and programming of the central nervous system could be used to treat the age-related declines in balance function (5,6). This is especially true for self-paced balance disturbances seen in ecological situations during projective rapid arm movements (7).

Age-related changes in postural control associated with rapid arm movements inducing self-paced perturbations of balance may be a cause of falls in older adults (8). During postural control associated with a rapid arm movement, voluntary arm movements are preceded by anticipatory postural adjustments (APA) (9,10). These responses (APA) are believed to be generated in a feedforward manner to counteract the upcoming mechanical perturbation associated with the arm movement. APAs are not fixed and are scaled to the mechanical characteristics of the focal movement (11), the direction of an upcoming perturbation (10), the initial stability of the postural system (12), and the target size (13). APAs demonstrate the capacity of the central nervous system to anticipate and integrate certain characteristics of focal movements into the motor program (14).

Several authors have demonstrated that APAs are delayed in older participants (7,15). Man'kovskii and colleagues (7) observed that postural muscles were activated at the same time as focal muscle, and Inglin and Woollacott (15) reported delayed APAs in older participants, but only in a choice reaction time (CRT) rather than in a simple reaction time (SRT) condition. It would be of interest to investigate whether APA can be improved in older adults as this is

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directly linked to potential improvements in their predictive capacities and estimation of self-generated perturbations.

In older adults, learning can improve motor control including the postural responses to external balance perturbations (16). Heiden and Lajoie (17) and Bisson and colleagues (18) have shown that virtual reality–based practice reduced the attentional demands of postural control and consequently improved functional balance in older adults. The usefulness of virtual reality as an original and fun way to increase motivation and the amount of task repetitions to favor at least indirect motor improvements has been reported in many studies [see (19) for a review]. Mirelman and colleagues (20) showed that virtual reality training can improve physical performance and gait during complex challenging conditions, as well as certain aspects of cognitive function in patients with Parkinson's disease. However, no studies have specifically investigated the effects of virtual reality–based training on the postural control associated with a rapid arm movement in older adults. We therefore aimed to determine whether postural control associated with an arm-raising task could be improved among aged individuals by using virtual reality–based training. We also wanted to determine whether these improvements are a result of central changes in motor programming. In daily life, sudden and protective arm movements are particularly challenging in terms of balance control. Accordingly, we designed a task in which participants were trained to perform rapid arm–raising movements from an upright standing position. We hypothesized that improvements in arm movement would be accompanied by improvements in postural adjustments, especially during the anticipatory period that precedes the arm movement. Such a finding would suggest central changes in motor programming. To further determine whether predictive capacities of self-perturbations can be improved and lead to more pronounced early postural adjustments, we varied the level of uncertainty under two different conditions. These were an SRT condition, where motor programming is specified in advance of the go-signal, which was compared with a CRT condition, where motor programming is specified after the go-signal.

MATERIALS AND METHODS

Participants

Sixteen adults participated in the present study after giving their written consent. The Regional Ethics Committee of Burgundy approved the experimental protocol, which was carried out in agreement with legal and international requirements (Declaration of Helsinki, 1964). Participants were randomly divided into two different groups (i) a the training group (TG) composed of eight participants, including two males and six females, and (ii) a control group (CG) composed of eight participants, including three males and five females. All participants were right handed (21) and were

at least 68 years old. The Tinetti test (22) (version with best score equal to 28), the one-leg stance test (all >5 seconds), and the timed up and go test were initially performed for a definitive selection of participants. Participants were asked about their usual physical and mental activities and history; all of the participants were in good health, with normal or corrected vision, and no participant suffered from any neurological, muscular, or cognitive disorder. All of the participants were retired, engaged in regular physical activity (~1.5 hours 2 days per week of walking, approved by a medical doctor), and at least one cognitive activity daily (reading newspapers or literature, doing crosswords). Their cognitive capacities were also evaluated by means of the Mini-Mental State Examination test (all scores ≥28). All participants received complete information about the experimental procedures, but none were informed about the various parameters that we assessed.

Apparatus and Experimental Procedure

To assess the effects of training, center of pressure (CoP) displacements and hand kinematics were measured during the two test sessions (pretest session and posttest session). The structure of the experiment was different in each group. Both the TG and CG were assessed at the pretest stage and 3 weeks later at the posttest stage, but only the TG participated in the six training sessions over the three intervening weeks. In the TG, a minimum interval of 48 hours was respected between the final training session and the posttest stage to avoid any direct influence of the final training session on the posttest.

Test sessions: pretest and posttest.—During the test sessions, hand movements were recorded using the Vicon system (OxfordMetricsGroup; sampling rate: 200 Hz) equipped with three cameras. After clinical assessment, participants received instruction about the arm-raising task: they stood upright on the force platform (feet were oriented on the force plate at a 15° angle on either side of the saggital plan, 15 cm between the two internal malleoli), the left arm down along the body and the right index finger pointing toward the ground, with an angle of between 30° and 35° between the arm and trunk. Participants were instructed to keep their eyes fixed on a horizontal bar placed 2 m from the floor and 2.5 m from the force plate. The force plate was placed flush with the floor. Three diodes were arranged on this horizontal bar, separated by 60 cm. The central diode was directly in front of the participant's right shoulder. Participants were asked to perform their movement in two conditions. In the first condition, the central diode was initially turned off. Participants were told to point with their index finger toward this central diode as soon as it was turned on (SRT). In the second condition, participants were told to point with their index finger toward the left or right diode, which was suddenly turned on. Participants were unaware of the location
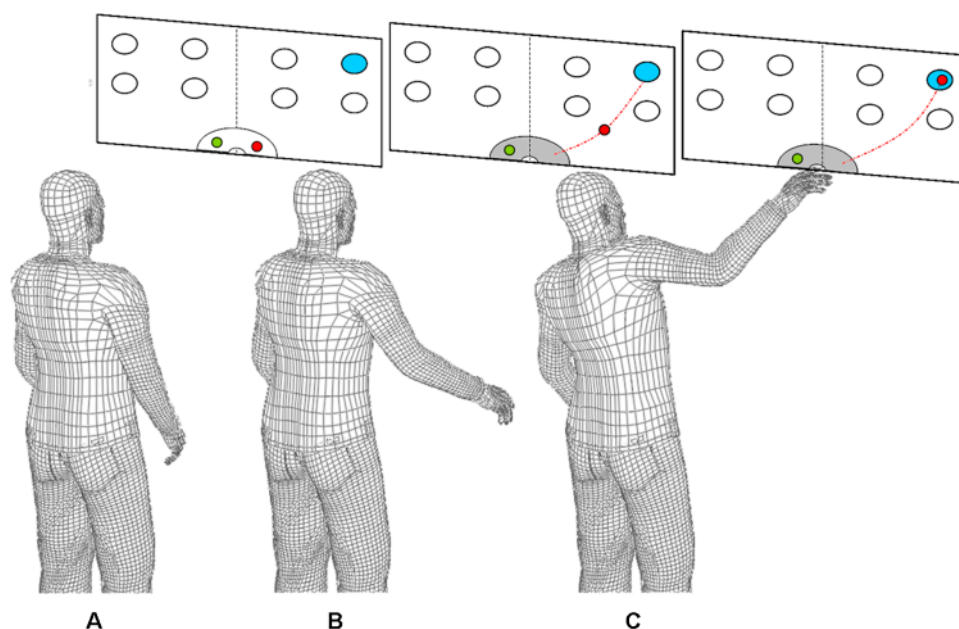
Figure 1. Representation of the position of the participant and the visual feedback during a training session. (**A**) Position at target appearance. (**B**) Position at midcourse during hand movement. (**C**) Position at the end of the hand movement.

(right or left) of the visual stimuli (CRT). In both conditions, participants were told to raise their arm as fast as possible and to start as quickly as possible after the appearance of the visual stimuli. They were asked to point to the direction of the diode, to remain for a few seconds with their arm in the air, and to move their index finger back toward the initial starting position. Before each trial, the participants were informed of the stimulation condition in which they were to perform the upcoming movement (SRT or CRT). To determine the effects of training in two different programming modes with various levels of uncertainty, we compared an SRT condition with a CRT condition. In SRT, motor programming is specified in advance of the go-signal, whereas in CRT, motor programming is fully specified only after the go-signal. The participants performed three trials only in each condition to limit any potential learning or relearning effect. Moreover, we chose to analyze three trials only, which is more representative of the risky and unpredictable reactive situations that may induce falls. These three trials per condition were performed in a random order.

Training session.—TG participants took part in six sessions (35–40 minutes per session, three sessions per week for 2 weeks) of virtual reality–based pointing exercises using an interactive training system; the set-up is an active motion capture system based on vision technology manufactured by Fovea Interactive. To imitate the short medical care treatments, such as those prescribed after falls, we chose six sessions over 2 weeks. We did not use the same motion capture system during the training sessions to provide visual biofeedback. These two systems were technically incompatible. This procedure also allowed us to exclude confounding factors by limiting potential contextual effects associated with familiarization with the prototype. Participants wore gloves with markers that were fixed on the index finger of each hand. Marker positions were tracked by the system, which was positioned in front of the participant at a standard distance depending on the participant's height. This prototype was placed underneath a large screen (200 cm × 130 cm, screen diagonal: 238 cm), onto which marker positions were projected. In this way, the movements of both the hands were represented on the screen, with a delay of 33 ms. The right index finger was represented by a red point and the left index finger by a green point. In the lower part of the screen, there was a half circle, which was the starting point. When the participant put both the hands on this circle, a target appeared somewhere on the screen (the radius of all targets was 10 cm), after a short variable delay (0.2–2 seconds) in a random position (eight standard positions: four in the right half of the screen and four in the left half). This was repeated over 30 trials. For each target, the reaction time and the peak velocity were recorded. At the end of the 30 trials, the means of these parameters were calculated and communicated to the participants. This feedback was given to the participants to help them maintain their motivation. During each training session, the participants were asked to perform three warm-up sequences and six sequences at maximum speed. They were invited to take a short break between each sequence (~2 minutes) Figure 1.
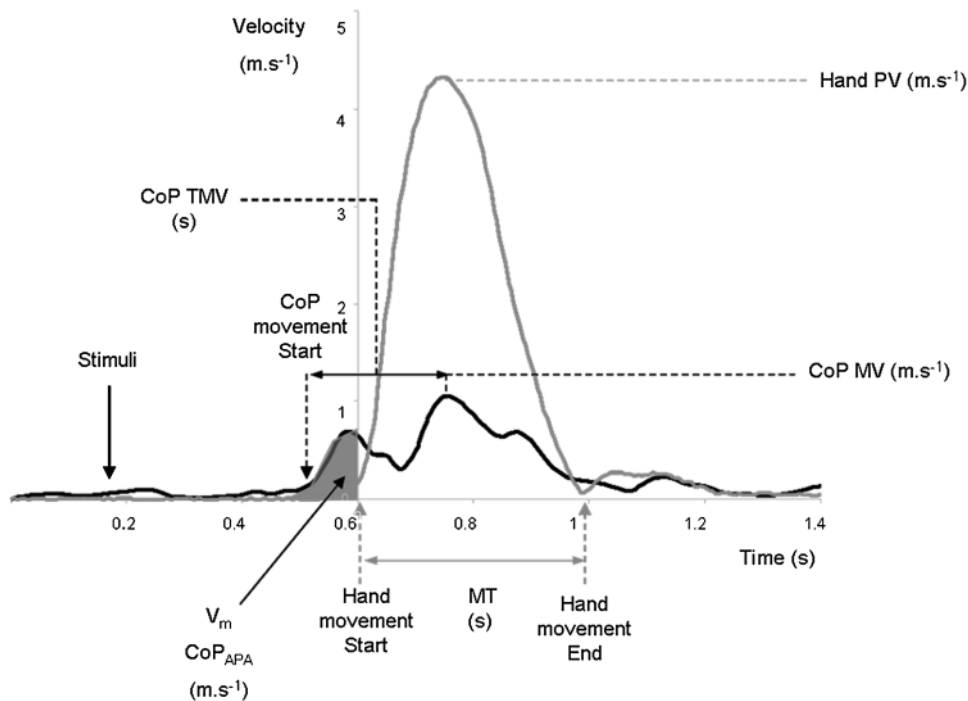
Figure 2. Schematic representation of the hand velocity profile (gray curve) and the center of pressure (CoP) velocity profile (black curve) from one trial in one participant with the parameters measured. Hand PV, hand peak velocity; CoP MV, CoP maximal velocity; MT, movement time; CoP TMV, CoP time to maximal velocity; and $V_m CoP_{APA}$, mean value of the CoP velocity during anticipatory postural adjustments. The CoP velocity curve scale has been modified (*5) for better visualization.

Data Recording and Statistical Analysis

During the test sessions, the x, y, and z displacement of the right index finger were recorded using the Vicon system (OxfordMetricsGroup; sampling rate: 200 Hz) with three cameras. The marker was placed on the nail of the index finger. Postural data were recorded using a seesaw force plate (techno concept ; Posturwin software, version P3-03). This force plate was connected to the Vicon system by an analogical signal to synchronize these two recordings. The recording of CoP displacement on an x-axis and y-axis began 600 ms before the hand movement procedure and finished 1,000 ms afterwards. Hand and CoP movement onsets were calculated from a 5% threshold of the maximal speed of each velocity signal. Hand and CoP–kinematics signals were filtered (fourth-order Butterworth with a 7 Hz low-pass cutoff frequency). To investigate the programming efficiency of the postural task, we focused on the initial part of the CoP displacement (7). The maximal velocity of the CoP displacement (CoP MV) and the time to CoP maximal velocity (CoP TMV: measured as the interval between the onset of the CoP displacement and the time to CoP maximum velocity) were taken as an indication of postural efficiency. More specifically, we focused on the time interval between the onset of CoP movement and the onset of hand movement. To measure APAs directly (7), we calculated the integrated value of the CoP velocity for this interval, divided by its duration (mathematically this represents the mean value of the CoP velocity that preceded the onset of hand movement: $V_m CoP_{APA}$). These parameters are shown in Figure 2.

All dependent variables were analyzed by repeated measures analyses of variance in which the factors were 2 Groups (TG and CG) × 2 Sessions (pretest and posttest). This analysis was carried out for the two conditions of stimuli independently (SRT and CRT). Levene's test for homogeneity of variance was conducted prior to the analysis of each variable. Post hoc analyses included Scheffé's tests when necessary. All statistical analyses were carried out using an alpha level of .05.

RESULTS

As a prerequisite, we verified that age (CG: 72.87 ± 3.09 years and TG: 71.50 ± 2.67 years), height (CG: 167.62 ± 5.82 cm and TG: 165.95 ± 9.81 cm), weight (CG: 66.00 ± 7.72 kg and TG: 62.82 ± 8.89 kg), Tinetti scores (CG: 27.00 ± 1.41 and TG: 27.50 ± 0.78), TUG scores (CG: 8.05 ± 0.88 seconds and TG: 7.92 ± 0.93 seconds), and Mini-Mental State Examination scores (CG: 29.13 ± 1.12 and TG: 28.87 ± 1.11) were similar in the two groups for the pretest session, $t(14) < 1.44$, $p > .171$.

Similarly, hand MT (CG: 0.434 ± 0.053 seconds and TG: 0.411 ± 0.045 seconds), hand PV (CG: 4.762 ± 0.867 m/s and TG: 5.155 ± 0.841 m/s), CoP MV (CG: 0.215 ± 0.049
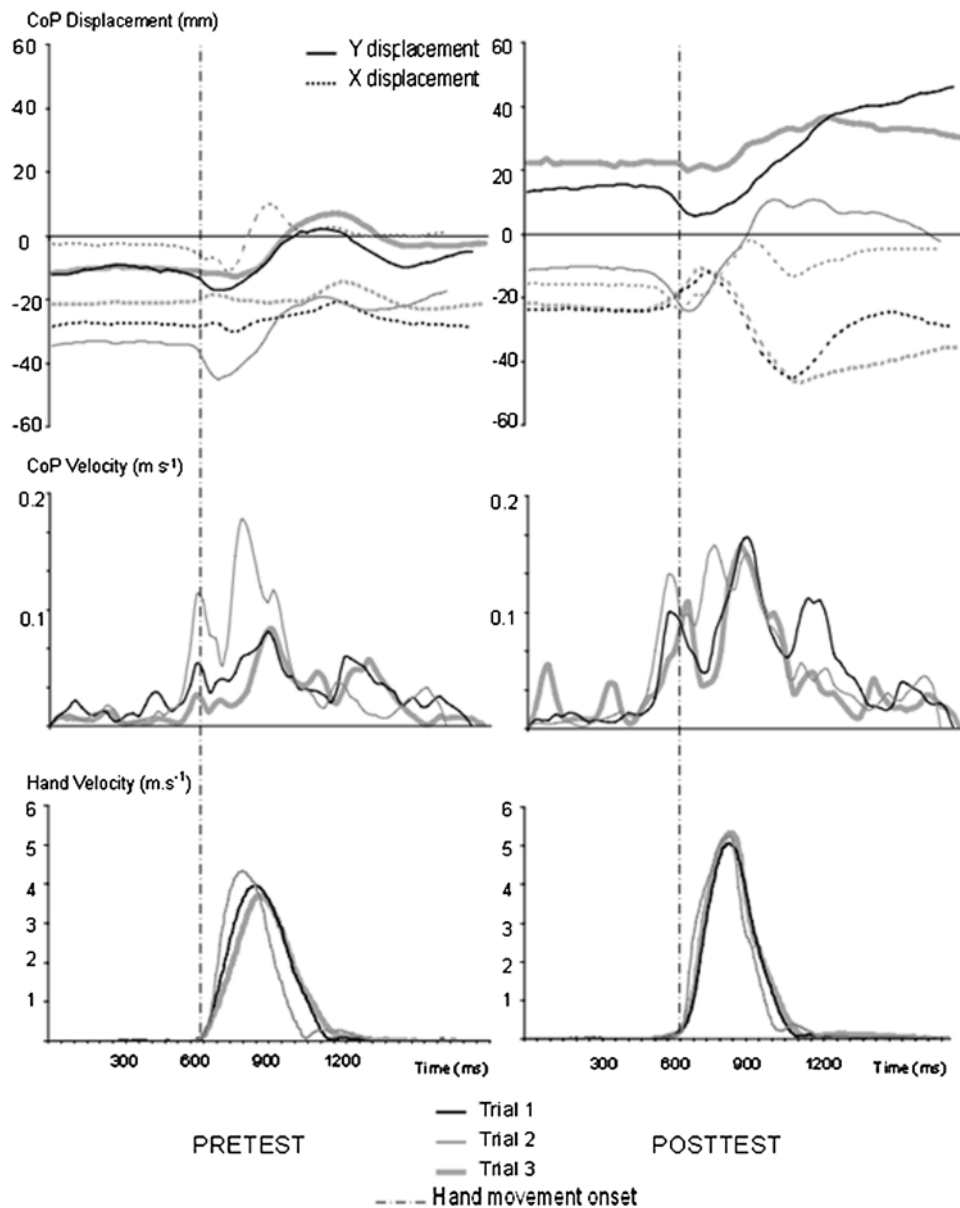
Figure 3. CoP displacement, CoP velocity profiles, and hand velocity profiles from one participant for three trials in the complex reaction time condition of the pre- and posttests.

m/s and TG: 0.181 ± 0.073 m/s), CoP TMV (CG: 0.158 ± 0.078 seconds and TG: 0.142 ± 0.049 seconds), and APA (CG: 0.058 ± 0.014 m/s and TG: 0.052 ± 0.036 m/s) in the two groups were found not to be significantly different for the pretest session, $t(14) < 0.921$, $p > .308$. Typical data for one participant, including three trials in pre- and posttest, are shown in Figure 3.

Hand kinematics

To verify that hand movement accuracy in the two groups was similar, we applied an analysis of variance to the x, y, and z positions of the hand movement end point. Results

demonstrated no main effect of group, $F(1,14) < 0.378$, ps > .548, and there was no Group × Session interaction, $F(1,14) < 1.764$, ps > .205.

Hand reaction times were computed as the interval between the appearance of the stimuli and the onset of the hand movement. There was no Group × Session interaction for this variable in either the CRT or the SRT condition, $F(1,13) < 0.803$, ps > .371.

In contrast, the results revealed that movement times decreased between pretests and posttests in the TG. The main effects of Session, $F(1,15) = 15.201$, $p = .001$, and Session × Group interaction were both significant, $F(1,15) = 14.008$, $p = .001$, respectively. Post hoc analyses revealed

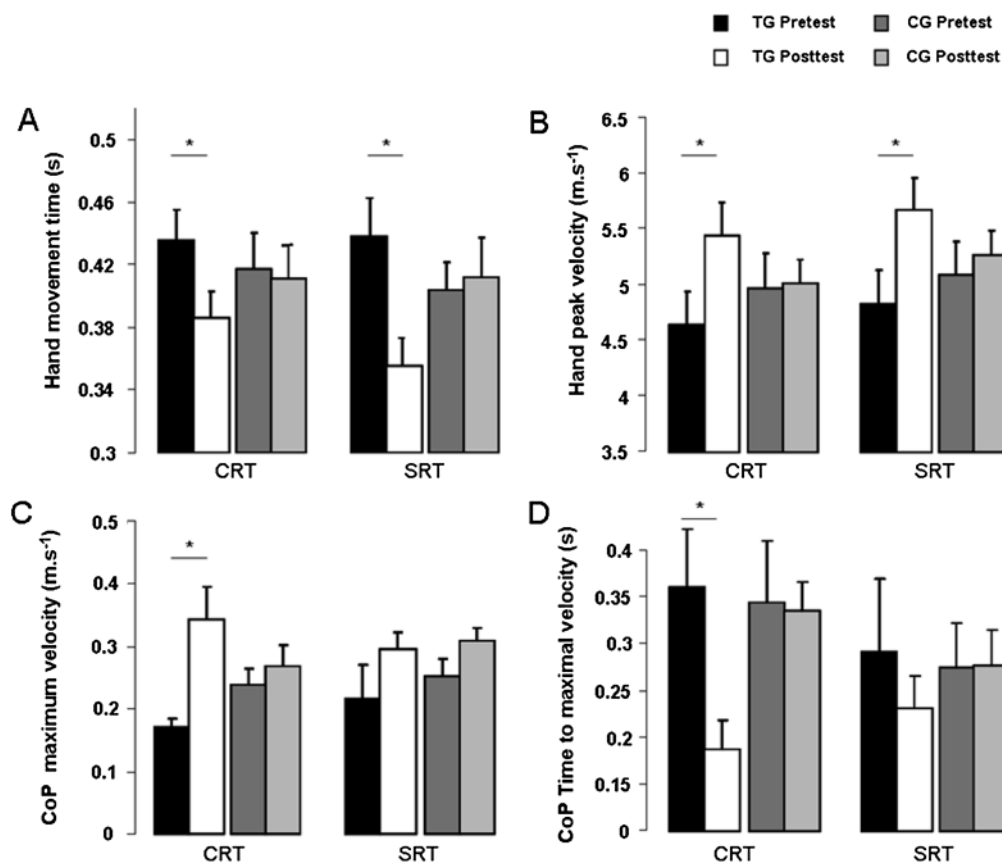Figure 4. Means of hand movement time (**A**), means of hand peak velocity (**B**), means of CoP maximal velocity (**C**), and means of CoP time to maximal velocity (**D**), in the training group (TG) and control group (CG) in the pre- and posttest sessions for the complex reaction time (CRT) and simple reaction time (SRT) conditions. Standard error is represented by vertical bars.

that movement times decreased in the TG in the two conditions of stimuli between pretests (CRT: 0.433 ± 0.019 seconds; SRT: 0.435 ± 0.024 seconds) and posttests (CRT: 0.384 ± 0.016 seconds; SRT: 0.354 ± 0.016 seconds). This was not the case for the CG, as shown in Figure 4A.

Similarly, hand movement peak velocity increased between pretests and posttests in the TG. The main effects of Session, $F(1,15) = 16.01$, $p = .001$, and the interaction of Session × Group, $F(1,15) = 10.681$, $p = .005$, were both significant. The decomposition of this interaction showed that the peak velocity increased in the TG in the two conditions of stimuli between pretests (CRT: 4.65 ± 0.29 m/s, SRT: 4.84 ± 0.32 m/s) and posttests (CRT: 5.46 ± 0.37 m/s, SRT: 5.75 ± 0.28 m/s). This was again not the case in the CG, as shown in Figure 4B.

Center of Pressure Kinematics

The CoP reaction time was computed as the interval between the appearance of the stimuli and the onset of the CoP displacement (with a threshold of 5% of the maximal velocity of the CoP). As reported above for hand reaction time, we found no significant effects in either the CRT or the SRT condition, $F(1,13) <1.166$, $ps > .301$.

In the TG, the maximum velocity of the CoP displacement increased between pretests and posttests only in the CRT condition. The main effects of Session, $F(1,14) = 12.404$, $p = .003$, as well as the Group × Session, $F(1,14) = 5.597$, $p = .032$, respectively, were both significant. The CoP maximum velocity was lower in the pretest (0.181 ± 0.073 m/s) than in the posttest (0.346 ± 0.052 m/s) in the TG, whereas these values were not significantly different in the CG (0.215 ± 0.049 m/s for the pretest and 0.271 ± 0.034 m/s for the posttest). In the SRT stimuli condition, the Group × Session interaction was not significant ($ps > .231$). These results are reported in Figure 4C.

The time to maximal velocity of the CoP (CoP TMV) displacement decreased between pretests and posttests in the trained group (TG) in the CRT condition only. The main effects of Session, $F(1,13) = 6.913$, $p = .020$, as well as Group × Session interaction, $F(1,13) = 5.038$, $p = .042$, were both significant in the CRT condition. Post ho*c* analyses revealed that the time to maximal velocity of the CoP displacement in the posttest test (0.166 ± 0.023 seconds) was significantly lower than in the pretest (0.297 ± 0.047 seconds, respectively). In the SRT stimuli condition, no significant effect was found ($ps > 0.245$). These results are reported in Figure 4D.
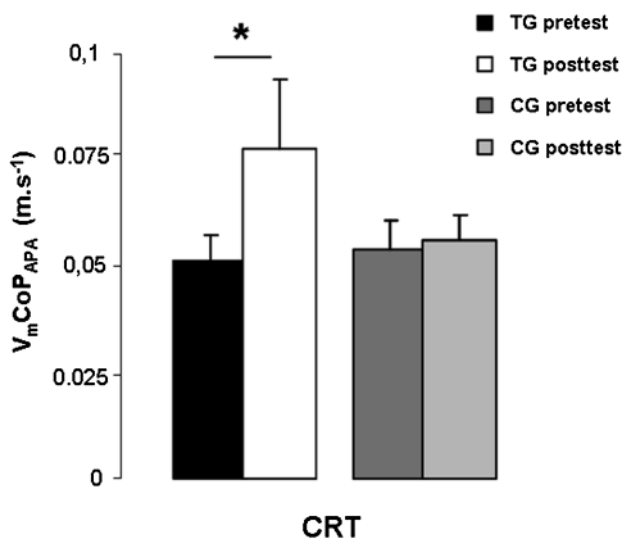
Figure 5. Mean values of mean velocity of CoP during APA (V_mCoP_{APA}) in the training group (TG) and the control group (CG) in the pre- and posttest sessions for the complex reaction time (CRT). Standard error is represented by vertical bars.

Significant effects on postural parameters were noted in the CRT condition only. To determine whether these changes reflect improvements in motor programming, we focused on the APA and calculated the mean CoP velocity before the onset of the hand movement (V_mCoP_{APA}). We found a significant Session × Group interaction, $F(1,14) = 4.622$, $p = .049$, for V_mCoP_{APA}. Post hoc analysis revealed that V_mCoP_{APA} was significantly higher in the posttest (0.078 ± 0.027 m/s) than in the pretest (0.052 ± 0.014 m/s) in the TG, as shown in Figure 5, whereas the mean duration of APA remains the same in the two sessions for this group (0.134 ± 0.056 seconds on average).

DISCUSSION

We aimed to determine whether postural control associated with a rapid arm movement in older adults could be improved using a virtual reality–based training program.

Our findings suggest that hand movement performance can be improved under the two conditions of stimuli in a series of six short training sessions each lasting approximately 30 minutes. Under the CRT condition only, the postural control associated with rapid arm movement in older adults can also be improved, especially in the initial phase of CoP displacement.

It is well known that movement slows down in elderly individuals (23). However, a few studies have reported practice-related improvements in the programmed part of a hand movement (24). In agreement with these reports, our results showed that practice resulted in a reduction in hand movement time and an increase in peak hand velocity.

In the CRT condition, which was the training condition, improvements in hand movement performances were accompanied by a decrease in time to maximal velocity of the CoP and an increase in the CoP amplitude. This impulse phase decreased to 166 ms on average, suggesting an improvement in motor programming (23). Focusing on the APA, we calculated the mean CoP velocity before the onset of the hand movement (V_mCoP_{APA}). Thus, we analyzed changes in the CoP velocity during the APA over a short duration of 130–140 ms. As the CoP displacement preceded the hand displacement, we consider that changes in V_mCoP_{APA} reflect changes of motor programming rather than feedback corrections. We observed that the mean CoP displacement velocity during APA (136 ± 56 ms before the onset of hand movement) increased between pre- and posttest in the CRT condition. In this case, feedback delays are probably too long to explain changes in V_mCoP_{APA} values between the pre- and posttest (25). This finding is interesting in the light of previous studies, which have shown delayed APAs in older adults (9,17). Our results strongly suggest that the programmed part of complex movements in older adults can be improved. The mechanisms of these improvements still remain undetermined: participants may increase hand velocity first and then APA would be adapted a posteriori to compensate for the perturbation associated with the arm movement or APA may be modified first to facilitate the execution of the arm movement (16).

The effect that we observed was limited to the training condition (CRT). In contrast, when the nature of the perturbation is well known in advance (SRT), the improvements seem more limited. This is because in a predictable environment (SRT), the motor programming is well defined in advance and specified before the go-signal. In contrast, when uncertainty increases, participants have to select between various solutions that may challenge motor programming (26,27). This finding is also consistent with the concept of contextual learning that explains the strengthening of motor learning during variable practice. This may induce greater solicitation of the motor memory compared with a blocked practice [see (28) for a review]. However, the present study did not directly compare these two modes of practice. Our study also has some other limitations. The sample size is not big enough to allow a full generalization of our results. We could have also used another placebo group for which a similar task would have been performed at a normal speed. In this group, we would expect no improvement for the programmed part of the whole movement. Finally, it would have been interesting to determine whether the observed improvements could have generalized to more functional and ecological situations, and further studies are currently under way to investigate this.

In conclusion, we measured practice-related improvements in the programmed part of postural control associated with an arm-raising task in a context of normal aging. It would be most interesting to determine the effects of this procedure in the context of a rehabilitation program for frail older adults with postural impairments.

REFERENCES

1. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. *Age Ageing*. 2006;35(suppl 2):ii37–ii41.
2. Guideline for the prevention of falls in older persons. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on falls prevention. *J Am Geriatr Soc*. 2001;49(5):664–672.
3. Prudham D, Evans JG. Factors associated with falls in the elderly: a community study. *Age Ageing*. 1981;10(3):141–14–6.
4. Skinner HB, Barrack RL, Cook SD. Age-related decline in proprioception. *Clin Orthop Relat Res*. 1984;(184):208–211.
5. Woollacott MH. Age-related changes in posture and movement. *J Gerontol*. 1993;48 Spec No:56–60.
6. Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: a review. *Neurobiol Aging*. 1989;10(6):727–738.
7. Man'kovskii NB, Mints AYa, Lysenyuk VP. Regulation of the preparatory period for complex voluntary movement in old and extreme old age. *Hum Physiol*. 1988;6(1):46–50.
8. Overstall PW, Exton-Smith AN, Imms FJ, Johnson AL. Falls in the elderly related to postural imbalance. *Br Med J*. 1977;1(6056):261–264.
9. Belen'kiĭ VE, Gurfinkel' VS, Pal'tsev EI. On elements of control of voluntary movements. *Biofizika*. 1967;12(1):135–141.
10. Aruin AS, Latash ML. The role of motor action in anticipatory postural adjustments studied with self-induced and externally triggered perturbations. *Exp Brain Res*. 1995;106:291–300.
11. Horak FB, Esselman P, Anderson ME, Lynch MK. The effects of movement velocity, mass displaced, and task certainty on associated postural adjustments made by normal and hemiplegic individuals. *J Neurol Neurosurg Psychiat*. 1984;47(9):1020–1028.
12. Aruin AS, Forrest WR, Latash ML. Anticipatory postural adjustments in condition of postural instability. *Electroencephalogr Clin Neurophysiol*. 1998;109(4):350–359.
13. Bonnetblanc F, Martin O, Teasdale N. Pointing to a target from an upright standing position: anticipatory postural adjustments are modulated by the size of the target in humans. *Neurosci Lett*. 2004;358(3):181–184.
14. Massion J. Movement, posture and equilibrium: interaction and coordination. *Prog Neurobiol*. 1992;38(1):35–56.
15. Inglin B, Woollacott M. Age-related changes in anticipatory postural adjustments associated with arm movements. *J Gerontol*. 1988;43(4): M105–M113.
16. Ooteghem VK, Frank JS, Horak FB. Practice-related improvements in posture control differ between young and older adults exposed to continuous, variable amplitude oscillations of the support surface. *Exp Brain Res*. 2009;199(2):185–193.
17. Heiden E, Lajoie Y. Games-based biofeedback training and the attentional demands of balance in older adults. *Aging Clin Exp Res*. 2010; 22(5–6):367–373.
18. Bisson E, Contant B, Sveistrup H, Lajoie Y. Functional balance and dual-task reaction times in older adults are improved by virtual reality and biofeedback training. *Cyberpsychol Behav*. 2007;10(1):16–23.
19. Holden MK. Virtual environments for motor rehabilitation: review. *Cyberpsychol Behav*. 2005;8(3):187–211; discussion 212–9. Review.
20. Mirelman A, Maidan I, Herman T, Deutsch JE, Giladi N, Hausdorff JM. Virtual reality for gait training: can it induce motor learning to enhance complex walking and reduce fall risk in patients with Parkinson's disease? *J Gerontol A Biol Sci Med Sci*. 2011;66(2):234–240.
21. Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*. 1971;9(1):97–113.
22. Tinetti ME. Clinical practice. Preventing falls in elderly persons. *N Engl J Med*. 2003;348(1):42–49.
23. Yan JH, Thomas JR, Stelmach GE. Aging and rapid aiming arm movement control. *Exp Aging Res*. 1998;24(2):155–168.
24. Yan JH, Dick MB. Practice effects on motor control in healthy seniors and patients with cognitive impairment and Alzheimer's disease. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn*. 2006;13(3–4): 385–410.
25. Cordo PJ, Nashner LM. Properties of postural adjustments associated with rapid arm movements. *J Neurophysiol*. 1982;47(2):287–302.
26. Hick WE. A note on one-tailed and two-tailed tests. *Psychol Rev*. 1952;59(4):316–318.
27. Fautrelle L, Prablanc C, Berret B, Ballay Y, Bonnetblanc F. Pointing to double-step visual stimuli from a standing position: very short latency (express) corrections are observed in upper and lower limbs and may not require cortical involvement. *Neuroscience*. 2010;169(2): 697–705.
28. Schmidt RA, Lee TD. Motor Control and Learning: A Behavioural Emphasis. 3rd ed. Champaign, IL: Human Kinetics Publishers; 1999; 3(11):298–310.