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Effects of task context during standing reach on postural control in young and older adults: A pilot study

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ABSTRACT

Reaching is an important component of daily activities with goals to interact and acquire objects in the environment. The task context of reaching, as determined by the behavioral goal and the properties of the object, can influence the control of posture and movements. This study examined age differences in postural stability during a forward reach under two task contexts, grasping versus pointing to a target. Young and older participants living in the community performed the tasks from the standing position. They reached forward, grasped or pointed to a target, and then returned to an upright posture as fast as possible. Postural stability was analyzed using the center of pressure (COP) during two phases of the task: the reaching movement phase and the returning movement phase. In the grasping context, the COP path deviations were significantly larger in older compare to young participants during both the reach and the return movement phases. In addition, during the return movement phase, only older participants showed a context-dependent increase in COP path deviations after grasping compared to pointing. The results highlight the impact of task context on postural stability during standing reach in young and older adults. Interventions for older adults with balance problems should consider incorporating activities that involve the interaction with objects of various properties in the environment. Future studies are necessary to investigate the factors underlying the person-environment interplay of postural control and the adaptation of anticipatory postural control associated with object interaction during functional tasks in older adults.

1. Introduction

Reaching is an important component of functional activities as the arms are used 8–9 h a day [1]. When the arm and trunk are coordinated to carry out reaching movements from standing, postural stability is essential to accomplish the task. Movements can disturb stability because of joint reaction forces and changes in posture [2]. Therefore, anticipatory postural adjustments are required to stabilize the posture before the perturbations associated with movements occur [2,3]. Subsequently, sensory feedback signaling imbalance triggers compensatory postural responses to restore stability [2,3].

Age-related changes in the physiological systems are known to cause deficits in postural control [4–6], leading to increased risk of falls [7], heightened morbidity, mortality, and cost of care [8]. A prospective study of community-dwelling older adults reported that 17.3% of falls occurred during reaching or leaning [9]. Another prospective study of older adults with a history of falls found that reaching or leaning accounted for about 5% of falls with moderate or severe injuries [10]. Moreover, 29.2% of injurious falls happened while people were engaged in diverse daily activities, such as cleaning, opening or closing doors [10]. While the major causes of falls included slip, trip, and leg weakness, the causes of more than 40% of falls remained unspecific or attributed to a loss of balance [10]. These results underline the need to further investigate the mechanisms of postural instability during daily activities. Because up to 95% of daily activities carried out by older adults involve movements of the arms and trunk [11], examination of age-related changes in postural control during reaching and learning may provide new insights into strategies for fall prevention.

Reaching tasks are primarily goal-oriented and require the individual to interact with objects in the environment. The central nervous system controls movements and posture based on the internal representation of the context, particularly the properties of

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objects and the predicted disturbances associated with interacting with objects [12]. The characteristics of a reaching target have been shown to alter postural response in a feedforward manner [13,14]. Wing et al. [15] instructed young adults to grasp a handle, and pull or push against a load. They found that the increase in the grasp force and ground reaction torques preceded any detectable change in the load force [15]. The results indicated that grasp and postural adjustments were pre-planned in anticipation of the perturbations induced by moving the load [15]. In a study by Mallau et al. [16], young and older adults grasped and lifted an object in standing. It was shown that center of pressure (COP) velocities and sway paths before and after grasping were similar between age groups [16]. Nevertheless, older adults applied significantly larger grasp force compared to young adults, reflecting a strategy to prioritize postural stability over grasping in older but not young adults [16]. To date it remains unclear whether the anticipatory postural control to reduce the perturbations associated with object intervention is affected by age. When standing subjects were exposed to predictable external perturbations, delayed and smaller anticipatory postural responses and subsequently, larger compensatory muscle activities to restore balance were found in older adults compared to young adults [17]. These results suggested that the effectiveness of anticipatory postural control is reduced with age [17]. In this connection, the ability to anticipate perturbations associated with object interaction at the end of reaching is likely altered with age. Based on the evidence of age-related declines in anticipatory postural control, older but not young adults may be less stable during reaching and grasping as compared to reaching only.

This study was a pilot study to investigate age differences in postural stability during standing reach between two task contexts, reaching and grasping versus reaching and pointing. To this end, participants grasped or pointed to a target at the end of a forward reach, and then returned to an upright position. It was expected that grasping would induce larger disturbances compared to pointing. The hypothesis was that the task context would influence postural stability in older adults but not young adults.

2. Method

2.1. Participants

Eight young adults (23.6 ± 3.0 years, 5 females and 3 males) and 10 older adults aged 65 years and over (74.1 ± 4.8 years, 6 females and 4 males) participated in the study. Young participants were recruited via emails and flyers at the University of Michigan. Older participants were recruited through advertisements and flyers. All participants were right-handed as assessed by the Edinburgh Handedness Inventory. Other inclusion criteria included the ability to walk without an assistive device, follow instructions in English, and not participating in competitive sport activities. Exclusion criteria included a history of diabetes, vestibular, ophthalmologic, neurological or debilitating musculoskeletal conditions, cognitive deficits as determined by the Mini-Cog test, binocular visual acuity at normal contrast less than 20/50, and impaired proprioception at the 1st metatarsophalangeal joint. The University of Michigan Institutional Review Board approved all procedures. Participants gave their written consent prior to data collection.

2.2. Procedure

Body weight, height, and foot length were measured. Participants stood barefoot with heels separated by 10% of body height. Foot positioning remained consistent throughout trials. The reach target was a cylinder (3.5 cm in diameter, 14 cm in height) placed at the height of xiphoid process and in front of participants in the mid-sagittal plane. Maximum reach distance was determined by instructing the participants to reach and point forward as far as possible without taking a step. The distance between the right acromion process at the start position and the distal end of third finger at the end position was the maximum reach distance. The task context was varied by the goals of reaching, i.e. grasping versus pointing to a target. For the pointing task, the target distance was 90% of maximum reach distance and measured from the right acromion process. For the grasping task, the target was at a distance of 90% of maximum reach distance subtracted by the length between the distal end of third finger and the middle of third metacarpal. With this adjustment, the reach distance was comparable between the pointing and grasping tasks.

The tasks required forward bending of the trunk as the arm reached towards the target (Fig. 1B). For the grasping task, participants grasped the cylinder by flexing all four fingers and the thumb to form a ring around the target. They reached to the target, grasped without removing it from the stand, and returned to upright. For the pointing task, participants reached forward, pointed to a yellow square (2.5 cm × 2.5 cm) on the cylinder with their index finger, and returned to upright.

Participants initiated the tasks at a self-chosen time with their right arm after a verbal "Go" command. They kept the feet in place while performing the task as fast and as many times as possible in a 20 s trial. Data from one 20 s trial for each task context were recorded. Participants rested for 2 min after completing each trial. The order of the tasks (grasp versus point) was randomized across participants.

2.3. Data collection

A motion capture system (MotionSTAR, Ascension Technology. Burlington, VT) recorded 3D kinematics of the reaching arm from a sensor placed on the radial styloid. A force platform (AccuSway, Advanced Mechanical Technology, Inc., Watertown, MA) recorded ground reaction forces and moments. The platform was zeroed after every trial and every rest break to prevent drift. The signals from the force plate were filtered by a built-in, primary 200 Hz low-pass, two-pole filter. The COP data were obtained using the Balance Clinic software (Advanced Mechanical Technology, Inc., Watertown, MA). Grasp force was measured using a strain gauge based force transducer embedded inside the target, which comprised of two polyetherimide half cylinders [18]. The strain gauge was a bonded foil compression load cell, with a measuring range of 0–1112 N, zero balance ±5%, repeatability rating ±0.1 of full scale, and hysteresis of 0.2% (Button mount model, Omega, Stamford, CT). It measured forces from multiple directions applied from all fingers during a whole hand grasp. The recording device for grasp force was calibrated before data collection. All data were collected at 100 Hz simultaneously using custom-written LabVIEW programs (National Instruments Corporation, Austin, TX).

2.4. Data processing

Arm movements, COP, and grasp force data were processed using custom-written Matlab programs (Matlab Version 7.5, MathWorks, Natick, MA). A zero-lag, 4th-order Butterworth filter (6 Hz cutoff) was applied. A 5% of peak velocity was the threshold to identify onsets/offsets of COP AP displacement and arm movements. Onsets and offsets of grasp force were determined using a threshold of 5% of maximum grasp force.

Arm movements and COP variables were analyzed in two phases of the task: (1) reach movement phase was the time when the movement was made towards the target, and (2) return movement phase was the time when participants returned to upright after grasping or pointing to the target (Fig. 1). The first repetition of reaching and returning movement from each trial was

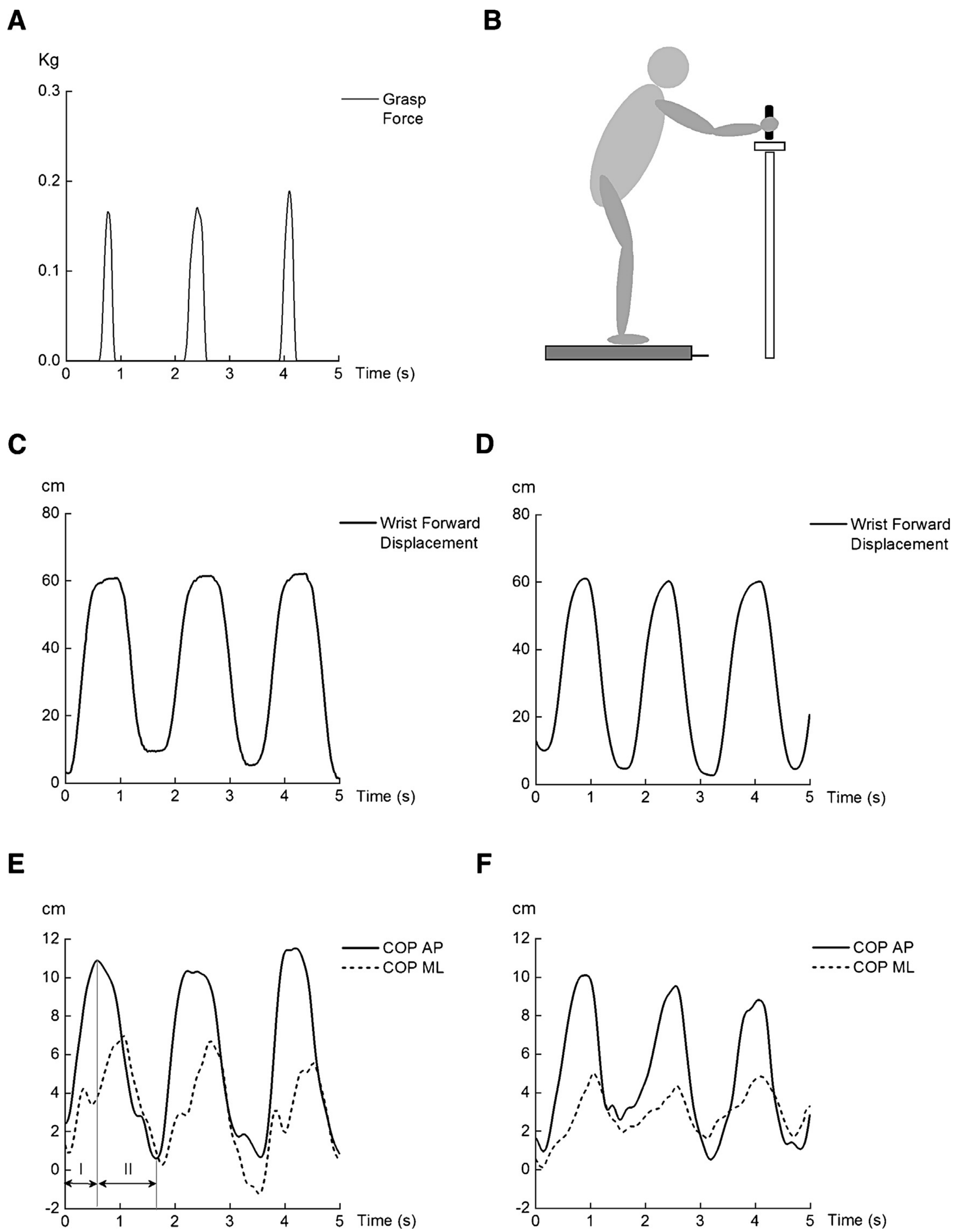

Fig. 1. The grasp force (A), wrist forward displacement to target (C), and center of pressure displacement in the anterior-posterior (COP AP) and medial-lateral (COP ML) directions (E) from three cycles of the reaching and grasping task performed by an older participant are presented. The period I corresponds to the phase of forward reaching movement towards the target. The period II corresponds to the returning movement towards the starting position after the acquisition of the target. The schematic representation of the reaching and grasping paradigm is shown (B). The wrist forward displacement (D) and COP AP and COP ML displacement (F) during three cycles of a reaching and pointing task from the same participant are shown.

excluded from the analysis. The subsequent eight repetitions within the trial were analyzed. The description for dependent variables is provided below.

The control of COP along a straight line has been used as a measure of postural stability in the limits of stability test [19,20]. Straighter COP paths indicate better dynamic balance [19]. COP path deviation was calculated by dividing the total length of COP path in the anterior-posterior (AP) and medial-lateral (ML) directions with the distance of the straight line connecting the onset and offset of the COP displacement (Fig. 2). A perfectly straight COP path has a ratio equal to one. Larger path deviations indicate that the COP paths are shifted further away from a straight line. In addition, the maximum forward displacement and peak AP velocities of the COP were also calculated.

The peak velocity of the arm during the reach and return movement phases was obtained. The coefficient of variation (CV)

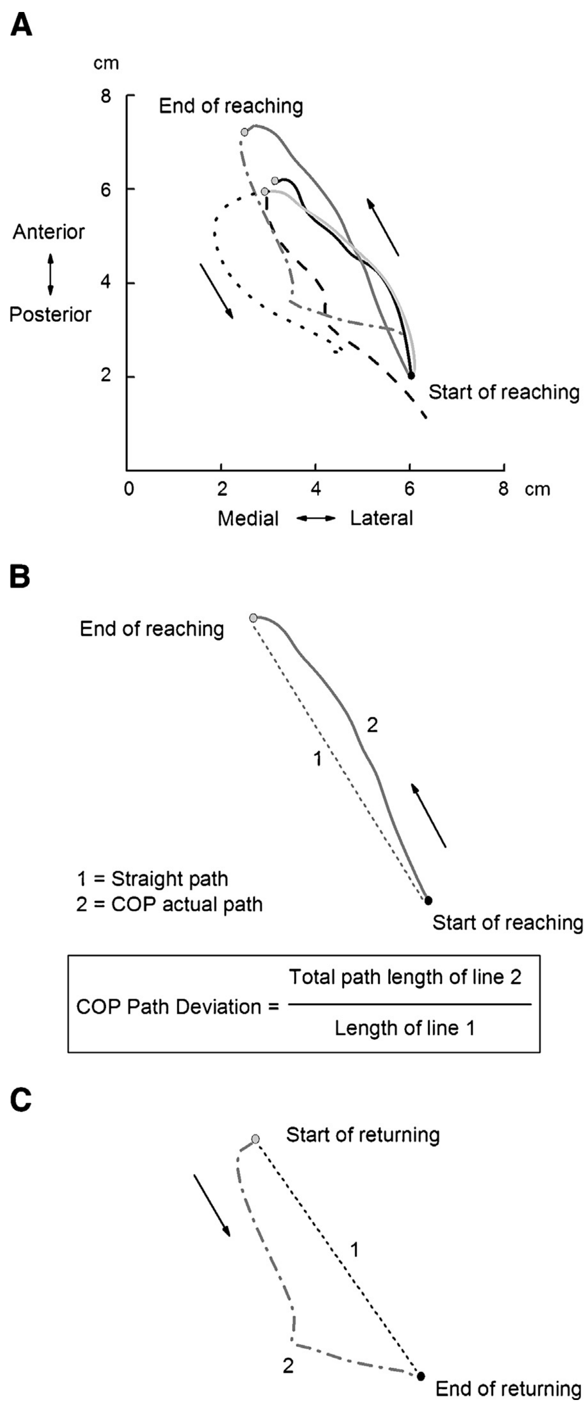

Fig. 2. Center of pressure (COP) trajectories during the reach and return phases from three movement cycles of the reaching and grasping task are presented in (A). (B) and (C) illustrate the calculation of COP path deviation during the reach phase and the return phase, respectively. The dash line (——) represents the straight line joining the onset and offset of COP displacement. Arrows (→) indicate the direction of the COP displacement.

of peak grasp forces from eight repetitions of the reach and grasp task was calculated to evaluate the variability of grasp forces. Grasp duration was from the onset to the offset of grasp force.

2.5. Statistical analysis

Statistical analysis was performed using the IBM-SPSS Statistics Version 21 (IBM-SPSS, Armonk, NY). This study was a repeated measures design, with group (young versus older) as between-subjects factor, and task context (pointing versus grasping) as within-subject factor. The characteristics of participants between groups were compared using independent sample *t*-tests. Dependent variables from the reach and return movement phases were analyzed separately in Linear Mixed Model. Tukey's LSD was used for post hoc analysis. The level of significance was $p < 0.05$.

3. Results

3.1. Characteristics of participants

No significant age difference was found in the variables of anthropometric measures and grasp performance (Table 1). The target and the reach distance was significantly greater in young than older participants ($p < 0.05$). For both young and older participants, the reach distance was not significantly different between the grasping and pointing tasks.

3.2. COP path deviation

As shown in Fig. 2, the COP moved forward towards the target during reaching. After grasping or pointing to the target at the end of reaching, the COP reversed its direction and moved backwards as the individuals returned to an upright position. Overall, older participants showed larger COP path deviations compared to young participants, reflecting an age-related increase in the deviations of COP path from a straight line (Fig. 3A). The interaction effect of group by context was significant during reaching towards the target ($p < 0.05$), and during returning to upright after grasping or pointing to the target ($p < 0.01$). The effects of group ($p < 0.01$) and context ($p < 0.001$) during the return movement phase were also significant. Post hoc analysis confirmed that in the grasping context, the COP path deviations were significantly larger in older compared to young participants during the reach ($p < 0.05$) and the return ($p < 0.001$) phase. In addition, during returning, only older participants showed significantly larger COP path deviations with grasping compared to pointing ($p < 0.001$).

3.3. COP maximum forward displacement and COP AP peak velocity

Regardless of the task context, young participants had significantly larger COP maximum forward displacement ($p < 0.01$) (Fig. 3B) and COP AP peak velocity ($p < 0.01$) (Fig. 3C) during the reach and return movement phases compared to older participants. No significant difference between grasping and pointing was found in either group.

3.4. Arm movement peak velocity

For both young and older participants, grasping had significantly faster arm peak velocity compared to pointing during the reach ($p < 0.001$) and the return ($p < 0.01$) movement phases (Fig. 4). The arm peak velocity was comparable between groups.

3.5. Peak grasp force, grasp force variability, and grasp duration

Older and young participants showed comparable grasp performance, including the amplitude and C.V. of grasp forces, and the duration of grasping (Table 1).

Table 1
Anthropometric measures, target distance, forward displacement of wrist during reaching to the target, and parameters of grasp performance in younger and older participants.

	Young (mean ± SE)	Old (mean ± SE)	*p* value
Body height (cm)	168.3 ± 2.15	169.9 ± 3.13	0.687
Body weight (kg)	60.1 ± 3.55	79.3 ± 8.91	0.086
Base of support			
Foot length (cm)	25.3 ± 0.42	26.1 ± 0.73	0.367
Stance width (cm)	33.0 ± 1.66	35.2 ± 1.93	0.417
Target distance (cm)	98.0 ± 1.79	88.5 ± 3.54	0.043[a]
Forward displacement of wrist during reaching			
Reach & grasp (cm)	56.2 ± 5.89	47.2 ± 8.29	0.020[a]
Reach & point (cm)	56.1 ± 5.33	47.2 ± 8.57	0.021[a]
Peak grasp force (kg)	1.7 ± 0.42	1.6 ± 0.34	0.641
C.V. of peak grasp force	0.17 ± 0.33	0.16 ± 0.03	0.453
Grasp duration (ms)	331 ± 52.0	396 ± 58.6	0.296

C.V. is coefficient of variation.
[a] Indicates $p < 0.05$ for the comparison between young and older participants.

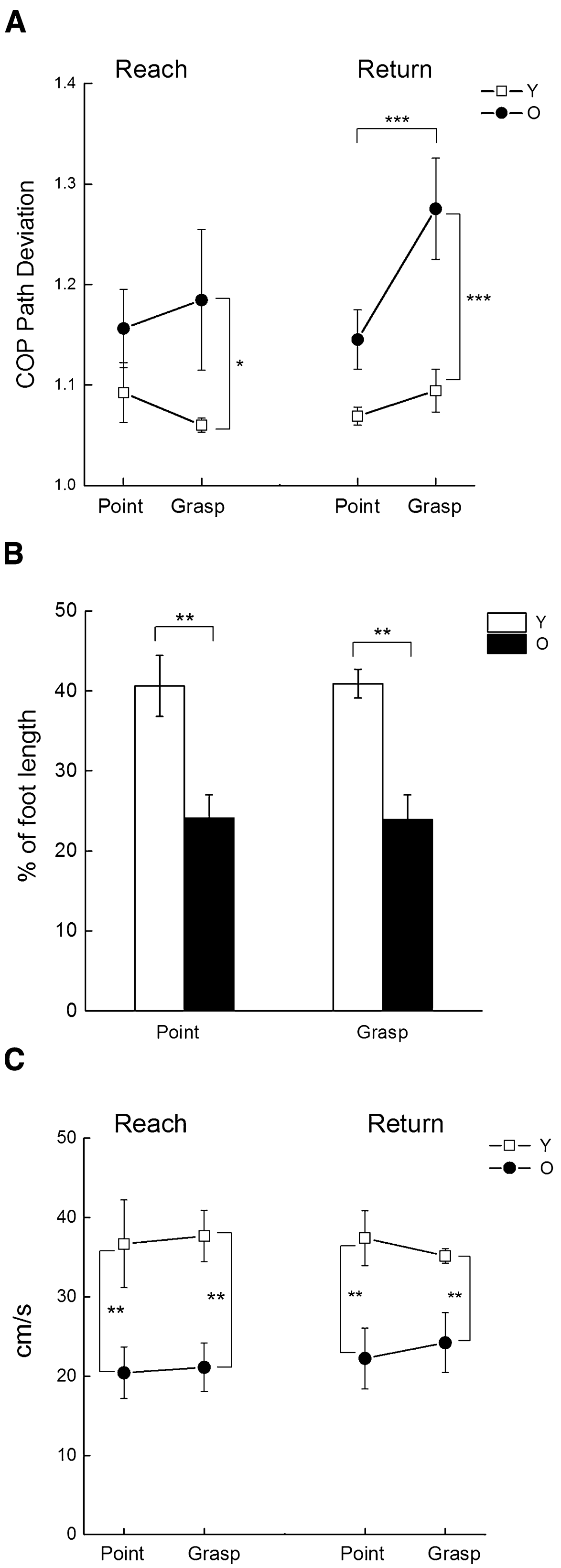

Fig. 3. Mean (±1SE) COP path deviations during the reach and the return movement phases in young (Y) and older (O) participants are presented (A). Larger COP path deviations indicate that the COP was shifted further away from a straight path. The effect of group was significant in the gasping context during the reach (*$p < 0.05$) and the return movement phases (***$p < 0.001$). During the return movement phase, the effect of task context (grasp versus point) was significant in older participants only (***$p < 0.001$). Mean (±1SE) COP maximum forward displacements expressed as a percentage of the foot length in young (Y) and older (O) participants are shown (B). The COP forward maximum displacement was significantly smaller in older than young participants (**$p < 0.01$). Mean (±1SE) COP peak velocity in the anterior-posterior direction during the reach and the return movement phases in young and older participants are shown (C). The COP peak velocity was significantly slower in older than young participants, regardless of the task context (**$p < 0.01$).

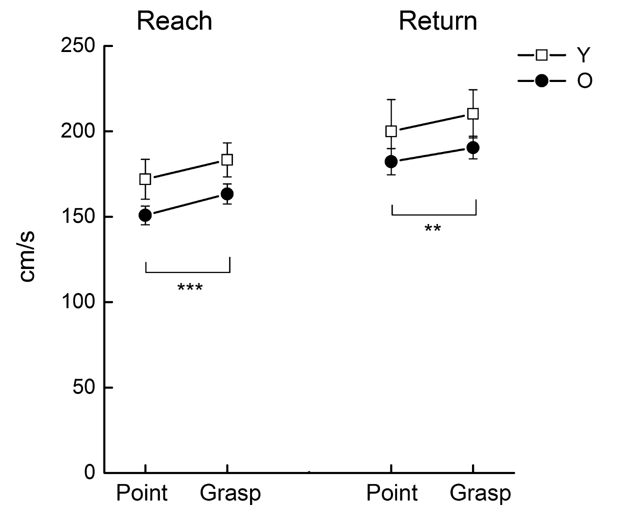

Fig. 4. Mean (±1SE) arm peak velocity was significantly faster in the context of grasping compared to pointing for both young (Y – open symbols) and older (O – filled symbols) participants during the reach (***$p < 0.001$) and the return (**$p < 0.01$) movement phases.

4. Discussion

This preliminary pilot study examined age differences in postural control during a forward reaching task with different goals, i.e. grasping vs. pointing to a target at the end of the reach. The tasks simulate real-life scenarios where reaching requires the individuals to interact with objects in the environment. Current results supported the hypothesis that postural stability is influenced by the context of reaching tasks in older adults. When the context was grasping a target, there was an age-related increase in COP path deviations before and after grasping. Moreover, during the return movement phase, only older participants showed larger COP path deviations after grasping compared to pointing. In contrast, the characteristics of COP paths in young participants remained unchanged regardless of the context. Taken together, current findings suggest that the ability to modulate postural control processes according to the demands of various task contexts during standing reach may be altered with age.

This study is the first to report an age-related increase in COP path deviations during reaching and grasping tasks. In standing, grasp forces are typically coordinated with anticipatory postural adjustments (APA) [15,16]. Moreover, grasp forces and APA are pre-planned according to the estimated disturbances associated with grasping and the sensorimotor memory about the object [15,16]. During grasping in standing, the anticipatory control of grasp forces was found to be preserved with age [16]. Conversely, studies have documented age-related changes in APA during arm movements, including altered muscle recruitment sequence [21,22], delayed onset [17], reduced duration [22] and amplitude [17] of APA in older adults compared to young adults. In this study, for young and older participants, the reach distance and the maximum forward COP displacement were comparable between the pointing and grasping tasks. Participants were able to reach forward to a similar extent regardless of the task context. Grasping could have caused larger disturbances because of the need to generate grasp forces [15,16], and the faster arm movements [2] during grasping than pointing. Larger COP path deviations in older adults after grasping compared to pointing may result from inadequate anticipatory postural stabilization [17,21–23]. Therefore, the acquisition of an object after reaching, as required in many daily activities, may present challenges to postural stability for older adults.

Alternatively, the age-related increase in COP path deviations during grasping could reflect an adaptation to declines in the physiological systems with aging [4]. During quiet stance, larger COP AP and ML displacements was found to correlate with lower scores of clinical balance tests [4], a history of falls and falls-related injuries in older adults [24,25]. This age-related increase in COP displacements during quiet stance likely serves as an exploratory strategy to acquire sensory information for postural control [26]. Murnaghan et al. [26] reported that COP ML displacements increased as the body's center of mass was stabilized in standing. Larger COP displacements may provide a continuous sensory inflow to the visual, vestibular, and somatosensory systems [26]. Consequently, the central nervous system can integrate the sensory information to formulate an accurate representation of the body's posture [26]. In this regard, during grasping, older participants could have increased COP movements to acquire additional sensory information in order to enhance postural stability.

Recently, studies have identified age-related differences in the characteristics of COP paths during voluntary movements performed in standing [27–29]. Compared to young adults, older adults had reduced smoothness in COP paths during reaching [28], made more adjustments to COP movements [29], and exhibited larger COP path deviations [27] during weight shifting. These age-related changes of COP paths have been linked to the speed and accuracy tradeoff [27,29]. While receiving real-time visual feedback about the position of COP, older adults were slower and less accurate in moving the COP to target locations compared to young adults, particularly with smaller and further targets [27]. In this study, for both young and older participants, COP AP peak velocities were comparable between grasping and pointing tasks. Therefore, speed-accuracy tradeoff could not explain current findings of context-dependent changes in COP path deviations observed among older participants. More importantly, it has been demonstrated that an instruction emphasizing an external focus on the consequences of movements, rather than an internal focus of the COP movement, could enhance balance performance [30]. Our participants directed their attention to an external focus, i.e. grasping or pointing to a target, rather than the internal focus of the COP movement itself. The characteristics of COP paths during voluntary movements may vary depending on whether the task goal was to control the COP position versus acquiring an object. More studies are necessary to elucidate age-related changes in the control of COP paths during goal-oriented tasks with an external focus as opposed to an internal focus.

5. Conclusion

In daily activities, arm movements are frequently performed to acquire objects. The demand to interact with objects necessitates anticipatory postural stabilization. This study provides important insights into the impact of task context on postural control in young and older adults. Interventions for older adults with balance problems should consider incorporating functional tasks that require the interaction with objects of various properties. Future studies are necessary to investigate the adaptation of anticipatory postural control in a novel and unpredictable situation, e.g. pushing an unknown weight, in older adults.

Conflict of interest

None declared.

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