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Effect of arm lifts on the center of pressure in quiet standing

BEV 3900, Master thesis in human movement science
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Norwegian University of Science and Technology
Trondheim, Norway, Spring 2010

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Acknowledgements:

I would like to thank my supervisor Professor Beatrix Vereijken at the Human Movement Science Programme for her patience, helpful support, and inspiring ideas. I would also like to thank PhD-student Yngve Sommervoll at the Human Movement Science Programme for his helpful and technical support. In addition, I thank my fellow master students for their support and good spirits.

I would also like to thank my father for his endless encouragement and support in my choice of education.

Abstract:

Background and aim: This study examines what effect arm lifts have on the movement of the center of pressure (COP) during quiet standing. Questions that were investigated were; is there evidence of Anticipatory Postural Adjustments (APA) in the opposite direction of upcoming arm movements and where is the COP positioned at the end of the arm lift?

Methods: A 500 Hz ProReflex motion capture system and AMTI force platform were used to capture the participants' unilateral and bilateral arm lifts in the diagonal, forward, and sideways direction. These measurements allowed for the APA and COP Arm Horizontal variables to be calculated.

Results: The results indicated that there was no evidence for APA in the opposite direction of the upcoming arm movements. Before lifting one arm sideways the participants leaned in the same direction as the upcoming arm lift. When the arms had reached their horizontal position, the COP was typically positioned in the forward direction. The COP was positioned further away from the baseline when the lifting had occurred in the diagonal and forward directions than in the sideways direction. When one arm had reached the horizontal position when lifting sideways, the COP was positioned in the same direction as the arm lift. **Discussion:** In contrast to prior studies, APA was in the same direction as the upcoming arm movement. As expected, the participants leaned in the forward direction when both arms had reached their horizontal position. The participants leaned in the same direction as the previous arm lift when only one arm was lifted in the sideways direction. Further analyses could focus on the COP movements during the arm lifts. The study can be extended to investigating how postural control is affected in other age groups and patient groups.

Introduction:

Posture is an essential function in our everyday lives. It has been defined as “the term to describe the orientation of any body segment relative to the gravitational vector” (Winter, 1995, p. 3). During standing and walking, people typically do an additional task simultaneously, such as carrying objects or doing the dishes. To be able to do these tasks in a safe manner, one depends on the body’s ability to control postural movements. Postural control has been defined as “a generic term to describe the dynamics of body posture to prevent falling. It is related to the inertial forces acting on the body and the inertial characteristics of body segments” (Winter, 1995, p. 3). The postural system’s main responsibility is to prevent falls and this is done by either sustaining, attaining, or reinstating the line of gravity above the posture’s base of support (BOS) (e.g., Pollock, Durward, Rowe, & Paul, 2000).

Postural control has three main functions. First, to be able to uphold the placement of the body’s segments in many different positions such as for example during sitting or standing. Second, to be able to respond to unexpected external and internal disruptions. Third, to be able to anticipate changes during a movement, and produce postural adjustments before, during, and after that movement (Cech & Martin, 2002). There are two main types of postural adjustment strategies, anticipatory and compensatory. An anticipatory postural control strategy includes a movement or enhancement in muscle activation before a foreseen movement takes place. In a compensatory postural control strategy, a reaction movement or muscle activation would arise after an unexpected movement has occurred (Pollock et al., 2000). These reactions could either be a `fixed-support` where the line of gravity is relocated while the BOS remains constant. This is usually achieved by body sway. Or it could be a `change-in-support` where the BOS is moved while the line of gravity stays unchanged. This is carried out either by arm or stepping movements (e.g. Pollock et al., 2000).

When conducting our daily routines, posture is constantly being challenged by the perturbations that occur during movements. Postural control has to cope with three types of external and internal perturbations: physiological, informational, and mechanical (Cech & Martin, 2002). During a physiological perturbation, a temporary internal event that interrupts the function of the neural control system might occur. An example of this is blocking of the afferent feedback information from the sensory systems which can happen as a result of diabetes (e.g. Cech & Martin, 2002). During an informational perturbation, there might be a

brief change in the environmental information, which again could have an effect on the feedback information from the sensory systems and the postural stability. This could occur when a person walks from a well lit room to a dark room, for example (e.g. Cech & Martin, 2002). Mechanical disruptions of posture are seen as a result of the forces that are generated by a movement, which in turn alters the forces that are acting on the body. A mechanical perturbation could be experienced either as an unintentional movement such as a sudden pull from a dog, or as a self-induced movement as when reaching for a cup of coffee.

In earlier investigations done on the coordination between posture and movements, different types of perturbation were used. In some studies posture was challenged by varying the participant's stance width, or having the participants close their eyes during quiet stance (Day, Steiger, Thompson, & Marsden, 1993; Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996; Ypsilanti, Hatzitaki, & Grouios, 2009). Different feet positions such as side-by-side stance, tandem stance, feet together, Romberg stance (heel-to-toe), and different foot angles have also been used as an internal perturbation to posture (Amiridis, Hatzitaki, & Arabatzi, 2003; Kirby, Price, & MacLeod, 1987; Yiou, Hamaoui, & Le Bozec 2007; Winter, Prince, Frank, Powell, & Zabjek, 1996). Another method that has been used to cause a perturbation is through movement of the arms. Here, the researchers either had their participants' reach, grasp, or perform different arm lifts (Aruin & Latash, 1995; Berrigan, Simoneau, Martin, & Teasdale, 2005; Bleuse et al., 2006; Kaminski & Simpkins, 2001). Most of the investigators that employed arm lifts used either unilateral or bilateral arm movements during their experiments (Aruin & Latash, 1995; Bleuse et al., 2005; Friedli, Cohen, Hallett, Stanhope, & Simon, 1988; Kaminski & Simpkins, 2001). An exception from this is found in the study done by Mochizuki, Ivanova, and Garland (2004), which made use of both unilateral and bilateral arm lifts at different speeds when investigating postural muscle activity.

Postural steadiness has been investigated in a variety of studies and with a range of different measures. The most typical measure of posture that will also be used in the present study is the center of pressure (COP). The COP is "the location of the resultant force exerted on the surface of a force plate" (Pachori, Hewson, Snoussi, & Duchene, 2008, p. 1). When both feet are touching the ground, the COP is positioned somewhere between the two feet depending on the weight distribution between the feet (Winter, 1995). The COP movements are measured in the horizontal plane in two planes, anterior-posterior and medial-lateral (Prieto et al., 1996). The position of the COP is seen as a mirror of the neural control of the ankle muscles (Winter,

1995). The COP is one of the most frequently used measurements in the study of postural stability (Winter, 1995).

The focus in earlier studies on COP trajectories and arm movements has mainly been on the role of Anticipatory Postural Adjustments (APA) (Stapley, Pozzo, & Grishin, 1998; Yiou, Mezaour, & Le Bozec, 2009). APA are presumed to minimize the perturbation that is generated by the force of the subsequent arm movement by creating a displacement of the COP backward before a forward lift of the arms is executed (Leonard, Brown, & Stapley, 2009). There are three main factors that could be effecting the initiation of the APA, the estimated size and path of the perturbation, the deliberate motor action related to the perturbation, and the postural task that is going to be performed (Aruin, 2002).

In some studies, the COP trajectories were only investigated in the anterior-posterior direction (Bleuse et al., 2005; Cuisinier, Olivier, & Nougier, 2005; Kaminski & Simpkins, 2001). In the studies that investigated both the anterior-posterior and medial-lateral directions, it was found that the changes in the medial-lateral direction were minor and could merely be a sign of negligible asymmetries in the movement (Aruin & Latash, 1995; Friedli et al., 1988; Yiou et al., 2009). However, in a study done by Winter et al. (1996), it was found that during quiet stance with feet side-by-side, there were two separate mechanisms operating. One was the ankle strategy, which was responsible for the anterior-posterior fluctuations. The other mechanism was the hip strategy, which accounted for the medial-lateral fluctuations. These findings were also supported by the studies done by Balasubramaniam, Riley, and Turvey (2000) and Rougier (2009). These studies suggest that it might be crucial to have a closer look at both directions when one wants to investigate how COP movements are affected by other movements.

There have been many investigations on the changes in COP before the onset of for example an arm movement. What most of these studies have found is an anticipatory movement in COP position in the opposite direction of the subsequent arm movement. Few studies have studied the COP position at the end of the arm movement (Hay & Redon, 2001; Le Bozec, Bouisset, & Ribreau, 2008). Where is the COP at the end of an arm movement? Does it show similar compensatory characteristics as the APA? In other words, is the COP at the end of the arm movement still positioned in the opposite direction, has it moved towards the baseline position, or is it positioned in the same direction as the arm movement?

The questions we want to investigate in the current study are:

- Do we find evidence of APA in the opposite direction of upcoming arm movements?
- Where is the COP positioned at the end of the upward arm movement?

To address these questions, we will study both unilateral and bilateral arm lifts to a horizontal position in the diagonal, forward, and sideways directions in young adults standing quietly. Both unilateral and bilateral arm lifts are important for activities of daily living (ADL), but we have little information about how these movements affect center of pressure. The three directions are chosen because in our daily lives, the things we need are not always right in front of us. We chose young adults because of the importance of having information on how posture is functioning in people without any known injuries or disorders that could influence their balance. This makes the dataset also suitable as a reference for further investigations on postural control in other age groups and patient groups.

Methods:

PARTICIPANTS:

The participants in this study were twenty-one young adults, eleven women and ten men, with a mean age of 23.0 years (± 1.52). For one of the female participants, the data from one of the hip markers was missing; therefore, this participant's data was excluded from further analysis. The participants were recruited from the university and college in the Trondheim area. None of the participants reported any history of injuries or disorders that could influence their balance. All the participants signed an informed consent before participating in the study. The study was approved by the local Regional Committee for Medical Research Ethics.

EQUIPMENT:

Ground reaction forces were recorded using an AMTI force platform (Advanced Mechanical Technology Inc., MA, USA; model BP 6001200). The force data were collected at 500 Hz. The force data recordings were synchronized with a motion capture system, which consisted of eight ProReflex cameras (Qualisys Medical AB, Sweden; model MCU 500), that recorded the arm lifts. Reflective spherical markers with a diameter of 19 mm were placed bilaterally on the acromion, trochanter major, and processus styloideus ulnae. Sample rate for the kinematic data was set at 240 Hz. All measuring equipment was calibrated each day before

use. The data were recorded on to a computer using Qualisys Track Manager (QTM) version 2.1 (Qualisys Medical AB, Sweden). The recorded signals were digitized, processed, and exported to Matlab version 7.4 R2007a (The Mathworks Inc., MA, USA) for further analysis.

PROCEDURE:

Before the participants arrived, they were given instructions to wear comfortable clothes and shoes with low heels. At arrival the participants were given written information about the experiment and were encouraged to ask questions. Before the testing started, the participants filled in a short questionnaire regarding their age, writing hand, how many days and hours they exercised per week, and if they were, or had been, competing in sports. The participants' weight, height, hip and waist circumference were also measured. The participant's feet were then placed in a square on the force platform. The length of the participant's shoes defined the size of the square (see Figure1).

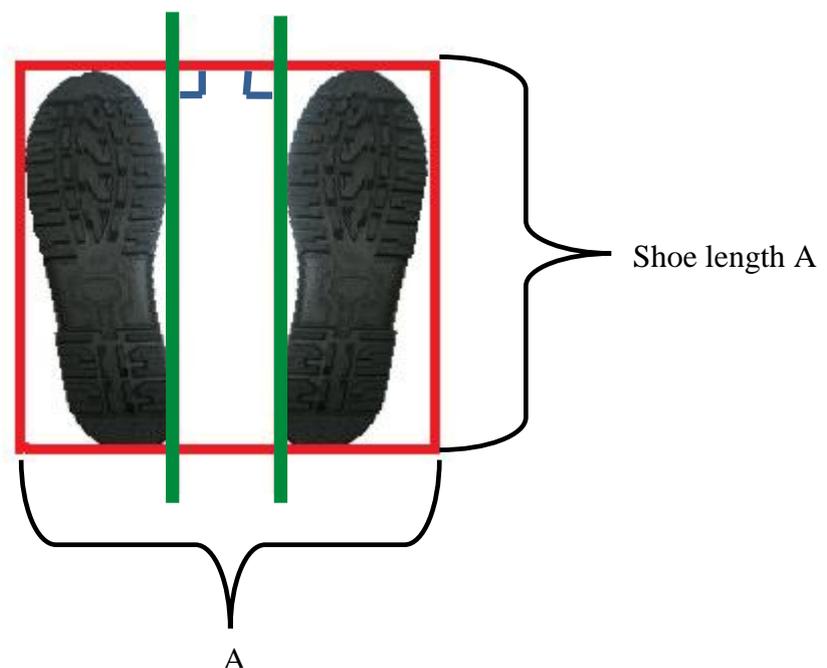


Figure 1: Position of the feet on the force platform. Stance width was defined based on the participants shoe length.

The instructions that were given to the participants before testing were to lift either one or both arms up to an approximately horizontal position in the diagonal, forward, and sideways directions. Each lift had to be done fast and determined. The experiment consisted of 3 different movements (arm diagonal, arm forward, and arm sideways) with the left arm, right arm, and both arms each, giving a total of 9 different conditions. Each condition consists of 5

repetitions, resulting in 45 trials for each participant. For the starting position, the participants had to stand relaxed and with their weight evenly distributed across their feet, looking straight ahead, and arms hanging comfortably by the side. Before each series of arm lifts, the participants were instructed by the researcher about which arm lift they were going to perform. Data recording began when the participant was in the correct starting position and indicated that they were standing as instructed. After 1 second the researcher indicated that the arm lift could start. Between each series of 5 repetitions, the participants were allowed to relax and move their body, except their foot position. A second researcher stood nearby the participants during the testing to ensure maintenance of foot position. When necessary, she reminded the participants about the instructions on how to perform the arm lift. The orders of arm lifts were counterbalanced across the participants.

DATA ANALYSIS:

Of the 9 conditions tested, current analyses will focus on comparing the 3 sideways conditions and the 3 both arm conditions. The both arms sideways condition will thus be used in two separate comparisons. The remaining 4 conditions, one arm forward or sideways, will not be analyzed in the present study. Out of the 5 repetitions that were done in each condition, the first three that were technically successful were used in further analyses. In the right arm sideways condition, one of the participants had only two repetitions that were technically correct, and these were used in further analysis. The force plate signals were filtered with a second order Butterworth filter, with a 10 Hz cut-off frequency. The plate measures resultant ground reaction forces and moments in the anterior-posterior, medial-lateral, and vertical directions of the force plate. These data were used to calculate the coordinates of the COP in the anterior-posterior and medial-lateral planes. The recorded ProReflex data were used to define the start and end of the arm lift (see Figure 2).

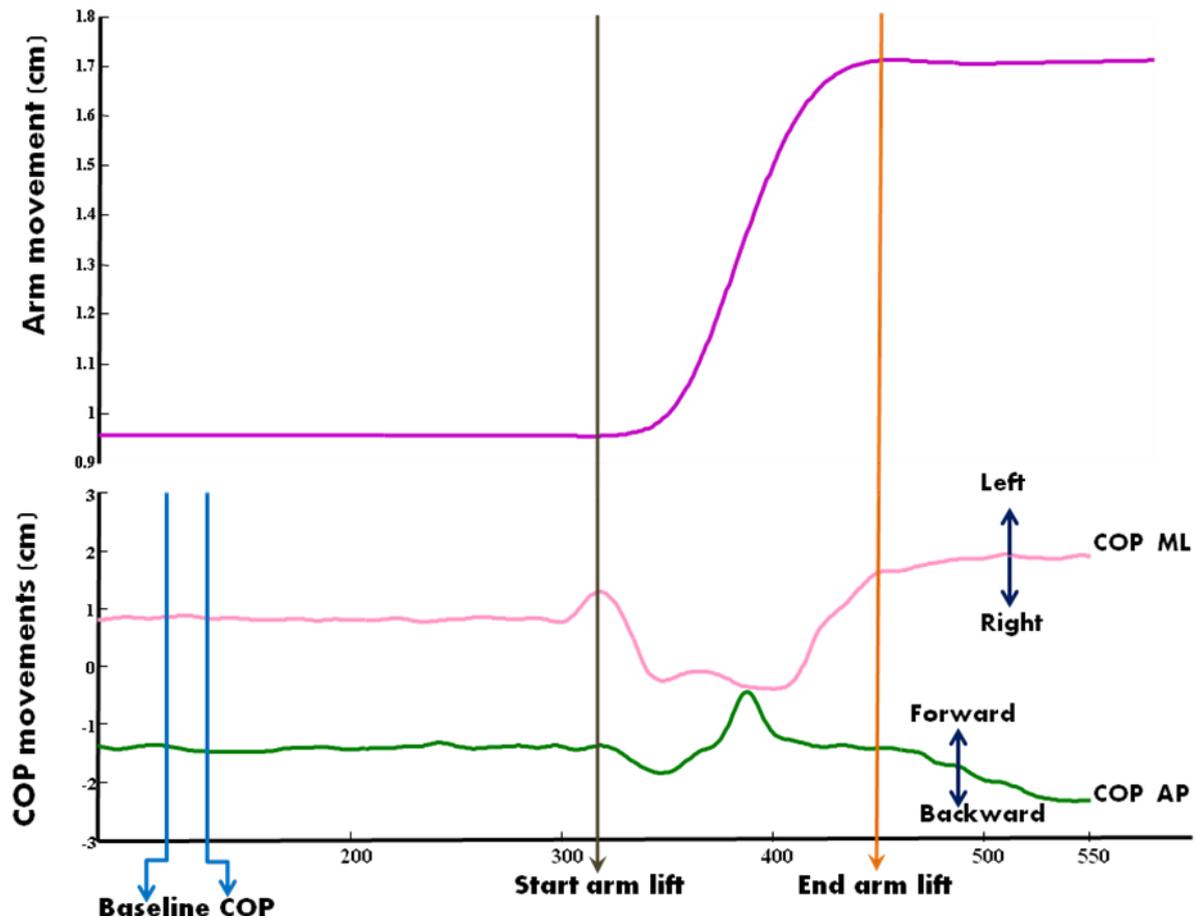


Figure 2: Exemplar data from a left sideways (LS) trial illustrating arm lift (top panel) and COP movements in the ML and AP planes (bottom panel). Vertical lines indicate the baseline COP, start and end of the arm lift.

Baseline COP was calculated in the X and Y dimensions as the mean COP X and mean COP Y between sample numbers 100-120. The start of the arm lift was defined as the last minimum before the arm started to move upward. The end of the arm lift was defined as the first maximum height of the wrist marker.

The variables COP_x Start and COP_y Start were the center of pressure coordinates in the X and Y dimensions at Start arm lift. The variables COP_x End and COP_y End were the center of pressure positions in the X and Y dimensions at End arm lift.

The baseline COP was defined as the origin (0, 0) and the variables Anticipatory Postural Adjustments (APA) and COP Arm Horizontal were calculated with respect to this origin. The APA variable was calculated as COP_x Start – Baseline COP_x and as COP_y Start – Baseline COP_y . The COP Arm Horizontal variable was calculated as COP_x End – Baseline COP_x and as COP_y End – Baseline COP_y .

Prior to statistical analyses, the participant's three trials per condition were averaged. In the statistical analyses, the mean, median, standard error of mean (SEM), and standard deviation (SD) were calculated. An independent-samples *t* test was performed to examine whether there were any gender differences for age, weight, height, waist and hip circumference, waist/hip ratio (W/H ratio), and body mass index (BMI). A mixed 2-way repeated measures analysis of variance (ANOVA) was first conducted on the COP variables with Condition as the within-subjects factor and Gender as the between-subjects factor. These analyses indicated that there were no significant gender differences or interaction effects, therefore the data were collapsed across both genders in further analyses. When the resulting one-way ANOVA indicated a significant effect for Condition, the results were followed-up using post-hoc comparisons with Bonferroni corrections for number of comparisons. All the statistical analyses were completed using SPSS 16.0 for Windows software (SPSS Inc., IL, USA). The level of statistical significance was set at $p < .05$.

Results:

The results are organized in different sections. The first section contains the participants' characteristics, the second section presents results on the preparation phase with the variable Anticipatory Postural Adjustments (APA) in the anterior-posterior and medial-lateral planes, and the last section results on the arm lift phase with the variable COP Arm Horizontal in the anterior-posterior and medial-lateral planes.

PARTICIPANTS' CHARACTERISTICS:

The age, writing hand, how many days and hours exercised per week, and current or prior participation in sports competition was reported by the participants. The weight, height, waist and hip circumference, body mass index (BMI), and waist/hip ratio (W/H ratio) were measured and calculated. The results of these measurements and calculations are presented in Table 1.

Table 1: Participants characteristics (N= 20). Mean \pm standard deviation for age, height, weight, hip and waist circumference, body mass index (BMI), and waist/hip ratio (W/H ratio) for men, women, and the total sample.

	Men	Women	Total
Age (years)	23.6 \pm 1.6	22.4 \pm 1.3	23.0 \pm 1.5
Height (cm)	175.0 \pm 10.0	168.2 \pm 7.3	171.6 \pm 9.2
Weight (kg)	79.2 \pm 11.4	70.0 \pm 8.3	74.6 \pm 10.8
Hip (cm)	99.8 \pm 1.9	101.0 \pm 1.5	100.4 \pm 1.2
Waist (cm)	84.0 \pm 1.9	76.5 \pm 1.6	80.2 \pm 1.5
BMI*	26.0 \pm 3.1	25.0 \pm 2.5	25.3 \pm 2.8
W/H ratio**	0.84 \pm 0.03	0.76 \pm 0.05	0.80 \pm 0.06

* BMI = Weight (kg)/Height² (m)

** Waist/hip ratio = Waist (cm)/Hip (cm)

An independent-samples *t* test showed that the men's waist circumference ($M = 84.0$, $SD = 1.9$) was significantly larger than the women's waist circumference ($M = 76.5$, $SD = 1.6$), $t(18) = 0.70$, $p < .008$ (two-tailed). It also showed that the men's waist/hip ratio (W/H ratio) ($M = 0.84$, $SD = 0.03$) was significantly larger than the women's waist/hip ratio (W/H ratio) ($M = 0.76$, $SD = 0.05$, $t(18) = 0.35$, $p < .001$ (two-tailed). For the other variables, there were no significant differences between the genders.

Out of the twenty participants, three (15%) stated that they were left-handed. The majority of the participants were physically active two to three days per week (median 3; 55%) and the duration of these activities was four to six hours per week (median 5; 44%). Furthermore, 35% of the participants were active in competitive sports, while 35% had never competed in any form of competition. The remaining 30% stated that at present they were not active in any competitive sports, though they had been active earlier.

PREPARATION PHASE:

The COP right before the arm lifts was measured in both the anterior-posterior and the medial-lateral planes. Figure 3 presents Anticipatory Postural Adjustments (APA) in the anterior-posterior plane before both arms were lifted in the Diagonal (BD), Forward (BF), and Sideways (BS) directions. As can be seen in Figure 3, the COP moves forward regardless of the direction of the upcoming arm lift. The COP seems to move more forward in the Forward condition ($M = 0.24$, $SEM = 0.08$) compared to the Diagonal ($M = 0.16$, $SEM = 0.07$) and Sideways conditions ($M = 0.11$, $SEM = 0.07$). The variability between the participants,

however, is large. A one-way ANOVA on APA in the anterior-posterior plane indicated that the three conditions were not statistically different, $F(2, 36) = 1.15, p = .327$.

Figure 4 presents APA in the anterior-posterior plan, before sideways lifts of one or both arms. As can be seen in Figure 4, the COP moves slightly forward regardless of the upcoming use of one or both arms. The COP seems to move more forward in Both arms lift ($M = 0.11, SEM = 0.07$) and the Right arm lift ($M = 0.12, SEM = 0.04$) compared to the Left arm lift ($M = 0.08, SEM = 0.05$). The variability between the participants is again large, however. A one-way ANOVA on the APA in the anterior-posterior plane indicated that the three conditions were not statistically different, $F(2, 36) = 0.17, p = .842$.

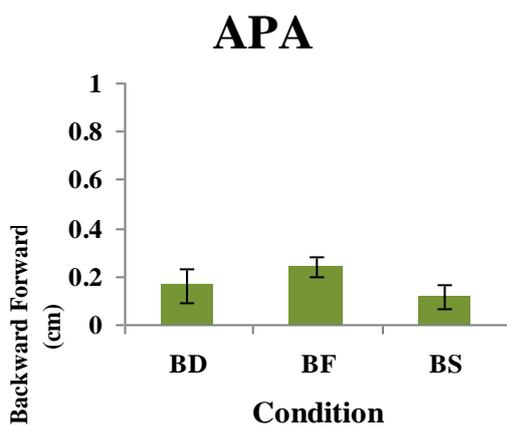


Figure 3: Forward and backward Anticipatory Postural Adjustments (APA) before both arms lifted in the Diagonal (BD), Forward (BF), and Sideways (BS) directions.

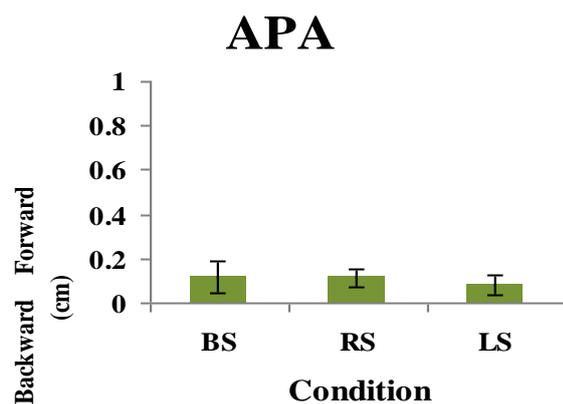


Figure 4: Forward and backward Anticipatory Postural Adjustments (APA) before sideways lifting of Both arms (BS), the Right arm (RS), and the Left arm (LS).

Figure 5 presents APA in the medial-lateral plane before both arms were lifted in the Diagonal (BD), Forward (BF), and Sideways (BS) directions. As can be seen in Figure 5, the COP moves somewhat to the left in preparation for the Diagonal condition and slightly to the right in preparation for the Sideways condition. When the arms were about to move forward, the anticipatory medial-lateral COP movements were minimal, but the variability between the participants was high. A one-way ANOVA on APA in the medial-lateral plane indicated that the three conditions were not statistically different, $F(2, 36) = 1.30, p = .286$.

Figure 6 presents the APA in the medial-lateral plane before the sideway lifts of one or both arms. As can be seen in Figure 6, the COP moves to the left in the preparation of a Left arm lift and to the right in preparation of a Right arm lift. When both arms were lifted, the COP moved slightly to the right, but the variability between the participants was large. A one-way ANOVA on APA in the medial-lateral plane indicated that there was indeed a significant effect for Condition, $F(2, 36) = 18.42, p = .001$, partial $\eta^2 = 0.51$. A post-hoc test with Bonferroni corrections for number of comparisons indicated that each of the three conditions was significantly different from both others, all p 's $< .03$.

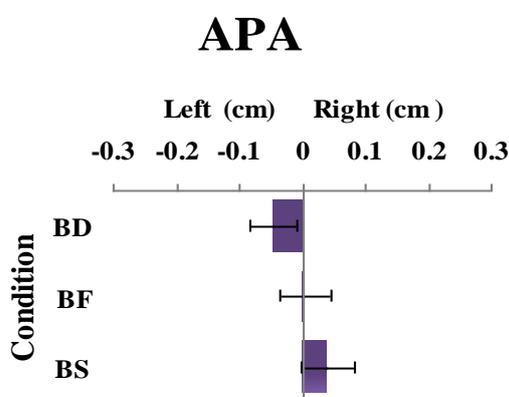


Figure 5: Left and right Anticipatory Postural Adjustments (APA) before both arms were lifted in the Diagonal (BD), Forward (BF), and Sideways (BS) directions.

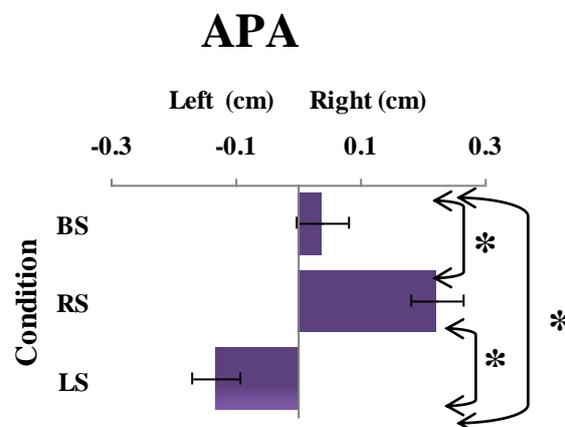


Figure 6: Left and right Anticipatory Postural Adjustments (APA) before sideways lifting of Both arms (BS), the Right arm (RS), and the Left arm (LS).

ARM LIFT PHASE:

The COP position was also measured in the anterior-posterior and medial-lateral planes when the arms reached a horizontal position. Figure 7 presents the COP Arm Horizontal in the anterior-posterior plane when both arms were lifted in the Diagonal (BD), Forward (BF), and Sideways (BS) directions. As can be seen in Figure 7, the COP is positioned forward at the end of the arm movement, regardless of the direction of the arm lifts. The participants seem to lean more forward in the Forward ($M = 1.82, SEM = 0.16$) and Diagonal conditions ($M = 1.70, SEM = 0.20$) compared to the Sideways condition ($M = 0.37, SEM = 0.10$). A one-way

ANOVA on COP Arm Horizontal in the anterior-posterior plane indicated that there was indeed a significant effect for Condition, $F(2, 36) = 37.06, p = .001$, partial $\eta^2 = 0.67$. A post-hoc test with Bonferroni corrections for number of comparisons indicated that the conditions Both Diagonal (BD) and Both Forward (BF) were significantly different from the Both Sideways (BS) condition, $p = .001$.

Figure 8 presents the COP Arm Horizontal in the anterior-posterior plane when one or both arms achieved a horizontal position after sideway lifts. As can be seen in Figure 8, the COP is positioned forward, regardless of the use of one or both arms. The participants seem to lean more forward in the Both arms lift ($M = 0.37, SEM = 0.10$) compared to the Right arm lift ($M = 0.32, SEM = 0.10$) and Left arm lift ($M = 0.30, SEM = 0.10$). The variability between the participants, however, was high. A one-way ANOVA on COP Arm Horizontal in the anterior-posterior plane indicated that the three conditions were not statistically different, $F(2, 36) = 0.31, p = .735$.

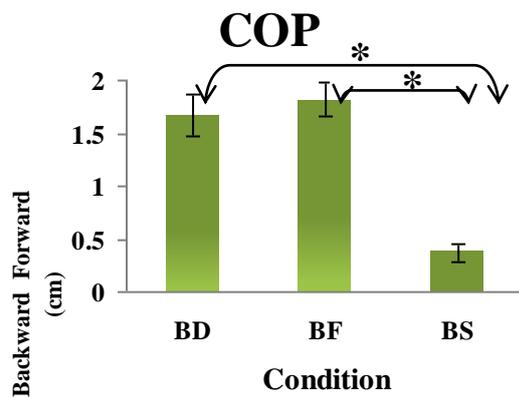


Figure 7: Forward and backward COP Arm Horizontal, when both arms were lifted in the Diagonal (BD), Forward (BF), and Sideways (BS) directions.

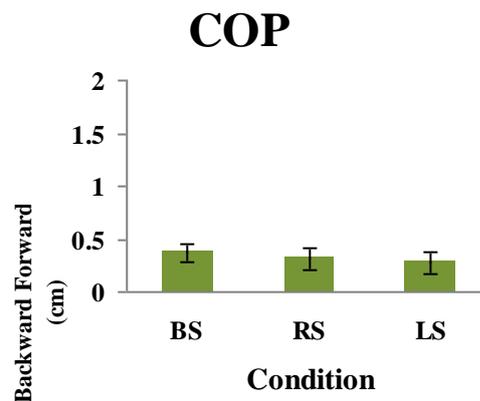


Figure 8: Forward and backward COP Arm Horizontal, after sideways lifting of Both arms (BS), the Right arm (RS), and the Left arm (LS).

Figure 9 presents the COP Arm Horizontal in the medial-lateral plane, when both arms reached a horizontal position in the Diagonal (BD), Forward (BF), and Sideways (BS) directions. As can be seen in Figure 9, the COP position was slightly towards the left in the Diagonal (BD) and Sideways (BS) conditions and towards the right in the Forward (BF) condition. However, the variability between the participants was large. A one-way ANOVA on COP Arm Horizontal in the medial-lateral plane indicated that the three Conditions were not statistically different, $F(2, 36) = 2.41, p = .104$.

Figure 10 presents the COP Arm Horizontal in the medial-lateral plane, when one or both arms reached a horizontal position after sideways lifts. As can be seen in Figure 10, the COP position was towards the left in the Left arm condition, and towards the right in the Right arm condition. In the Both arms condition, the COP had moved minimally compared to the baseline position. A one-way ANOVA on COP Arm Horizontal in the medial-lateral plane indicated that there was indeed a significant effect for Condition, $F(2, 36) = 18.40, p = .001$, partial $\eta^2 = 0.51$. A post-hoc test with Bonferroni corrections for number of comparisons indicated that each of the three conditions was significantly different from both others, all p 's $< .008$.

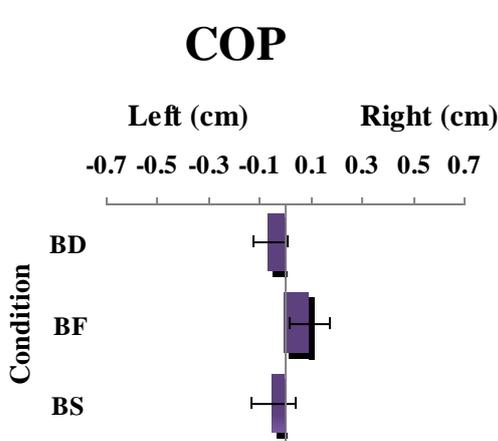


Figure 9: Left and right COP Arm Horizontal, when both arms were lifted in the Diagonal (BD), Forward (BF), and Sideways (BS) directions.

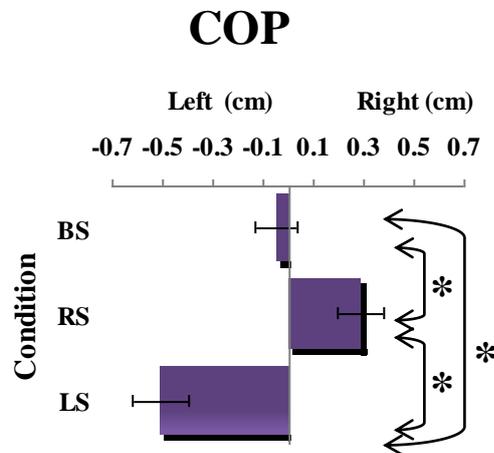


Figure 10: Left and right COP Arm Horizontal, after sideways lifting of Both arms (BS), the Right arm (RS), and the Left arm (LS).

Discussion:

The aim of this study was to examine what effect arm lifts have on the movements of the center of pressure (COP) during quiet standing. Two questions were put forward, is there evidence of Anticipatory Postural Adjustments (APA) in the opposite direction of the upcoming arm lifts, and where is the COP positioned at the end of the upward arm lift? The results showed that there is no evidence of APA in the opposite direction of the arm movements. All the participants in this study leaned forward during the preparation for the upcoming arm lift. Before lifting one arm sideways, the participants leaned in the same direction as the upcoming arm lift.

When the arms had reached their horizontal end position, the COP was typically in the forward direction as well. In addition, the results showed that the participants were leaning more forward when both arms had reached a horizontal position in the diagonal and forward lifting directions than in the sideways direction. When one arm had reached the horizontal end position when lifting sideways, the COP was found in the same direction as the arm lift.

There were no gender differences in the findings.

ANTICIPATORY POSTURAL ADJUSTMENTS (APA):

Before the upcoming arm lifts the participants leaned in the forward direction, regardless of which arm would be used and the direction of the arm lifts. This is opposite of what was found by Aurin and Latash (1995) and Bleuse et al. (2005), who found that the participants had a backward shift of the COP right before an upcoming forward arm lift. In the study done by Aurin and Latash (1995), the results also showed that before the arms were lifted sideways, the participants did not move in the anterior-posterior plane. The latter was also found in the current study. What is interesting with the current findings is that although the COP movements are small they are all in the forward direction. Additional examination would be needed to find out the underlying reason for these findings. Nevertheless, one has to wonder why the present study's findings are so different from what other studies have found. One reason could be the diverse protocols used in the different studies. For example, the base of support size was found to have an influence on the APA in a study done by Yiou, Hamaoui and Bozec (2007). When the stance width increased so did the APA's amplitude. In this study, the stance width was based on the participant's shoe-length while the Bleuse et al. (2005) study does not mention how the participant's feet were placed on the force platform. Given the findings in the Yiou, Hamaoui and Bozec (2007) study, not having a standardized

stance width could have had an effect on the findings of Bleuse et al. (2005). An additional factor that may have had an influence on the findings is how the arm movements were performed. In the study done by Bleuse et al (2005), they asked their participants to grasp a handle that was in front of them. In the current study, the participants were asked to lift their arms to a horizontal position in a firm movement. Bleuse et al. (2005) found that the speed of the arm movement influenced anticipatory COP movements, but the speed of arm movement was not controlled in the present study. A final reason for the differences in the findings could lay in the different data analyses that have been used in the different studies. For example, both the Aurin and Latash (1995), the Bleuse et al. (2005), and the current study used different methods when defining the onset of the arm movement. The onset of arm movement was defined by the use of EMG signals in the Aurin and Latash (1995) study while in the Bleuse et al. (2005) study the onset of the arm movement was defined as the onset of angular velocity. In the current study, the ProReflex data was used to define the onset of the arm movement using vertical movement of the wrist.

As expected, there were no differences between the lifting directions in the medial-lateral plane when both arms were lifted nor was there any particular COP movement pattern between the lifting directions. This was to be expected since a shift either to the left or right side would be unnecessary during the preparation phase of bimanual arm lifts. These findings are consistent with the findings in the study of Aurin and Latash (1995). Other studies that investigated APA in the medial-lateral plane also found that there only were small COP changes in the medial-lateral plane and that these changes could merely be a sign of small asymmetries (Friedli et al., 1988). This might be the reason why some studies excluded the medial-lateral plane when they started the testing (Yiou et al., 2009). In further investigations there should be more focus on the medial-lateral plane, despite the finding that the COP changes that occur there are small. The reason for this is that the studies done by Winter et al. (1996) and Rougier (2009) found that the mechanisms that are responsible for the fluctuations in the two planes are different from each other. Therefore, to be able to get a better understanding of how the COP movements are affected by arm lifts, one should look at both the anterior-posterior and medial-lateral planes and not just the anterior-posterior plane.

The results also showed that there were differences between the unimanual and bimanual arm conditions before the sideways arm lifts were performed. Before the participants lifted one arm sideways they leaned in the same direction as the upcoming arm lift. Before both arms were lifted sideways the participants were positioned at the baseline. It was expected that

anticipatory COP movements would occur before lifting one arm and that there would be minimal movement before both arms were lifted, but the direction that the anticipatory COP movement took place in was not anticipated. A shift towards the right seems to be the consistent pattern before the participants performed a sideways right arm lift and the COP seems to move further away from the baseline position before the participants lift their right arm than before they lift their left arm. It would be interesting to know whether this pattern is merely a coincidence or whether this could have something to do with the use of the preferred versus non-preferred arm. To be able to answer this question one should examine a group of left-handed people to see if they present the opposite effect.

CENTER OF PRESSURE (COP):

When both arms had reached their horizontal positions, the results showed that the participants were leaning forward. There was also a difference between the three lifting directions. The participants were leaning further forward when their arms had reached a horizontal position in the diagonal and forward directions than in the sideways direction. The latter finding was as expected. Since the sideways arm lift occurs in the medial-lateral plane one would not anticipate that the COP in the anterior-posterior plane would be positioned far away from the baseline position.

The results also showed that it mattered whether one arm or both arms were lifted sideways. With only one arm lifting, the COP was in the same direction as the prior movement, whereas it was approximately centered after both arms were lifted sideways. Here, the participants seemed to be leaning further away from the baseline position when their left arm had reached the horizontal position than when the right arm had reached the horizontal position. The explanation for this pattern might be found in a study by Ypsilanti et al. (2009). They found that during lateral aiming tasks there were smaller perturbations when the participants used their preferred (right) arm than the non preferred (left) arm. They argued that these findings might be related to the postural muscles on the preferred (right) side being more capable than the non-preferred (left) side to counteract the postural perturbations produced during arm lifts, thus making the COP movement smaller. This is an intriguing possibility that needs further investigation. Again it would be interesting to examine how these patterns are for people that have the left arm as the preferred arm. Are they the opposite of what has been found here or are there other explanations?

The results showed that when the arms had reached their horizontal position after sideways lifts, the COP was positioned somewhat forward. There were no differences in the COP position pattern depending on the use of one or both arms. These findings were as expected. As the arm lifts occurred in the medial-lateral plane, the COP need not be positioned far from the baseline in the anterior-posterior plane.

The results also showed that when the arms had reached their horizontal position after sideways lifts, there was no consistent pattern between the use of one or both arms. This might be related to the high variability between the participants, making it difficult to find significant differences in the COP position for the three arm lifts compared to the baseline position.

LIMITATIONS:

During the testing the participants were instructed to lift their arms fast and firm up to an approximately horizontal position. There was no device indicating when the participants' arms had reached this horizontal position, so it was up to the participants to decide when they had their arms horizontal. This might have varied somewhat between the different trials and the participants, influencing the findings. Furthermore, there was also no standardization on how fast the arm lifts were to be done. Although the participants were given some practice trials before the testing, during the testing they seemed sometimes unsure on how fast they should do the lifts and several were instructed to lift faster. Both of these factors could have had an effect on the findings. In a study done by Mochizuki, Ivanova, and Garland (2004), they found that during bilateral and unilateral arm lifts the COP displacements were scaled according to the movement speed. In the Bleuse et al. (2005) study, they found that right before the participants performed a self-paced unilateral arm lift there was a shift of COP backward. However, right before a slow arm lift they found no evidence of APA. A possible solution that might minimize the first limitation could be to have some type of object that is put at the participant's horizontal position so when they touch this object they know that the arm is at its horizontal position. For the speed-related limitation, one could use some type of metronome and instruct the participants to follow that. As a result, one could get a more standardized and uniform velocity.

Another factor that might have affected the results in this study is that in the analyses, the averages of the participants' three trials were taken. Using the average rather than the individual trials can have influenced the results especially in the case of high individual

variability, because it does not take into consideration if some of the measured trials have higher or lower values than the rest of the measurements. Further analysis of the individual trial might shed more light on these issues.

Having the participants wear comfortable clothes and shoes with low heels may also have had an influence on the findings. In other studies such as Kirby, Price and MacLeod (1987) and Yiou, Hamaoui and Le Bozec (2007), they made their participants stand barefooted on the force platform to get their optimal measurements, as wearing shoes might help the participants stabilize their balance. Furthermore, by not having restrictions on what the participants could wear, some participants may wear loose fitted clothes. This could cover the reflective spherical markers or influence the measurement of the movement patterns. This problem was also the reason why one of the participants was excluded from the analysis in the present study, as one of the hip markers was obscured by clothes. Testing participants in their underwear or thigh fitting clothes would be an alternative, but this has other drawbacks, for example when you want the current study to be used as a comparison for patient groups or elderly. Furthermore, when one wants to investigate tasks that occur in the context of people's daily life activities (ADL), one should try to make these as realistic as possible. Since most of us wear clothes and shoes (outdoors or some form of indoor shoe) during the day it would be more comparable to have the participants also wear it during the testing.

FUTURE RESEARCH:

This study has focused on a few variables occurring during two phases of arm lifts, but there are several other variables in this data set that can be examined. Other factors that might be of interest are to find out whether there is a correlation between the COP movements and the arm movements? What is the amplitude of the COP movements before and at the end of these different arm lifts? And does the acceleration and velocity of the arm lift have an effect on the location and movement of the COP?

It would also be interesting to investigate other measurements that have been collected in this study but that were not included because of the time limits. Some examples of questions that might be of interest are; what happens to the COP during the arm lifts? Where is the COP located at the end of the trial, when the arms are back to their starting position? What happens to the COP before, during, and at the end of the unilateral arm lifts in the forward and diagonal directions? One could also look further at the topic concerning the use of the preferred and the non-preferred arm.

To take this study a step further would be to compare these young adults against other age groups or find out more about how the posture is affected by different diseases. If one is able to find some answers to these questions, one might get a better understanding of how we can maintain our balance while performing other movements or tasks. These findings could again be used as a standard or reference when one wants to investigate people that have problems performing two tasks at the same time, people with balance problems, or those who are at risk of falling.

In summary, the results indicated that for young adults, there was no evidence of APA in the opposite direction of an upcoming arm lift. The findings also show that when both arms had reached the horizontal position, the COP was positioned in the forward direction, and when only one arm was lifted in the sideways direction, the COP was positioned in the same direction as the arm lift. Further investigations could assess whether people with various neurological diseases or elderly people display these same patterns.

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Appendix:

Participants questionnaire: The questionnaire about the participants age, writing hand, how many days and hours they exercised per week, and if they were, or had been, competing in sports. And the participants' measured weight, height, hip and waist circumference.

Alder: _____

Hvilken hånd skriver du med: _____

Spørsmål:

1) Hvor mange dager i uka driver du idrett, eller mosjonerer du så mye at du blir andpusten og/eller svett? Sett bare ett kryss

- Hver dag
- 4-6 dager i uka
- 2-3 dager i uka
- 1 dag i uka
- Sjeldnere enn en gang i uka
- Sjeldnere enn en gang i måneden
- Aldri

2) Til sammen hvor mange timer i uka driver du idrett eller mosjonerer du så mye at du blir andpusten og/eller svett? Sett bare ett kryss

- Ingen
- Omtrent ½ time
- Omtrent 1-1½ time
- Omtrent 2-3 timer
- Omtrent 4-6 timer
- 7 timer eller mer

3) Deltar du i idrettskonkurranser, kamper? Sett ett kryss

Ja Nei, men jeg deltok før Nei

Målinger:

Høyde(cm)	Vekt(kg)	Midje(cm)	Hofte(cm)