The Effect of Body Orientation on a Point-to-Point Movement in Healthy Elderly Persons

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OBJECTIVE. Upper limb retraining during the early phases of neurological rehabilitation often involves having individuals practice reaching in body orientations that reduce the effect of gravity on various joint motions (e.g., shoulder flexion, elbow extension). However, the efficacy of these training techniques has not been determined. The purpose of this study was to determine the effects of reducing gravity through a change in body orientation from sitting to side-lying on the kinematics of a point-to-point movement in healthy elderly persons.

METHOD. Nine healthy, right-hand-dominant women 62 to 66 years of age pointed to a target in two different body orientations—sitting and side-lying. A 2-dimensional kinematic analysis of the movement was performed to compare the trajectory of the hand and the interjoint coordination under the two conditions.

RESULTS. Regardless of body orientation relative to gravity, participants produced straight hand paths and smooth, bell-shaped velocity profiles. However, they moved slower in side-lying, and the pattern of interjoint coordination varied. The shoulder and elbow moved less, whereas the scapula made a greater contribution to the overall movement. Furthermore, the temporal coordination of the joints was modified as a consequence of body position.

CONCLUSION. The results indicate that point-to-point arm movements made against gravity differ from those made in a gravity-reduced plane, particularly at the joint level, illustrating that movement organization is sensitive to this contextual difference. The effect of minimizing gravity on upper limb movement needs to be explored in patient populations to determine whether training patients in gravity-reduced orientations is efficacious.

Although having patients begin reaching in gravity-reduced body orientations is a common clinical practice, the efficacy of this training has not been determined (Duff, Shumway-Cook, & Woollacott, 2001). In fact, little is known in general about what happens to upper limb movement as a consequence of changes in body orientation. Given the current press for therapists to engage in evidence-based practice (Holm, 2000; Tickle-Degnen, 2000), empirical evidence to support or refute this practice technique is needed. This study provides a first step in determining the efficacy of training in gravity-reduced body orientations by investigating the kinematics of a multijoint pointing movement in healthy elderly persons.

**Literature Review**

Relatively few studies have investigated the consequence of changing body orientation relative to gravity on upper limb movement. Savelbergh and van der Kamp (1994) reported that changing body position produced differences in the number and duration of reaches attempted by infants; it is not known, however, whether their reaches were organized differently. A kinematic analysis would allow for a detailed description of the reaching movement in terms of its spatial and temporal organization, providing useful information not available at the observational level. (For a review on the kinematic parameters of reaching movements, refer to Trombly and Wu [1999].)

Because altering limb orientation relative to gravity differentially affects the recruitment patterns of the deltoid muscle (Michiels & Bodem, 1992), and activation patterns of postural muscles are influenced by body orientation (van der Fits, Klip, van Eykern, & Hadders-Algra, 1998), it is reasonable to suggest that the dynamics of multijoint arm movements also will change. Consequently, the kinematic profiles of the movements may differ as well. Unfortunately, studies attempting to elucidate the influence of whole body orientation, or body segment orientation, relative to gravity on movement kinematics have produced varied results.

Smetanin and Popov (1997) found that gravity differentially affected pointing errors when participants attempted to point to remembered locations in three different body orientations. They proposed that the motor plan was not modified to account for differences in gravity during pointing movements. Consistent with this notion, Schiller, Ostry, and Gribble (1999) found that rotation and translation of the jaw differed with respect to head orientation relative to gravity during speech utterances, suggesting that the central nervous system did not completely compensate for the relative changes in gravity produced by the differing head orientations.

In contrast, Papaxanthis, Pozzo, and Stapley (1998) reported data suggesting that gravitational torque may be incorporated into trajectory planning during performance of vertical pointing movements in healthy adults. They found that movement duration and peak velocity were consistent, regardless of the movement direction relative to gravity. However, the velocity profiles differed with respect to movement direction such that movements made against gravity had a shorter acceleration phase, suggesting that the central nervous system planned the trajectories differently with respect to gravity. Although these studies suggest that body orientation relative to gravity may affect the planning and execution of movements, the nature of these differences has not been described clearly, particularly with regard to the coordination between the shoulder and elbow joints. This interjoint coordination is of particular interest because this coordination is indirectly being addressed during the early phase of upper limb retraining in neurorehabilitation. Additionally, all of the studies cited used young participants. It has been well established that aging affects the flexibility of the musculoskeletal system (Cavanaugh et al., 1999; McGill, Yingling, & Peach, 1999) and that reaction time, movement time, and velocity profile smoothness of pointing movements differ between the young people and those of advancing age (Teeken et al., 1996; Yan, 2000; Yan, Thomas, & Stelmach, 1998). Additionally, movement trajectories seem to be more variable in elderly persons than in younger persons (Darling, Cooke, & Brown, 1989). Considering the patient population of interest to occupational therapists working in adult neurorehabilitation is generally elderly, information regarding the influence of body orientation on arm movements within the healthy elderly population would be particularly useful.

The purpose of this study was to investigate the influence of eliminating the effects of gravity relative to the direction of limb movement by altering whole body orientation from sitting to side-lying. This study provides the first step in answering the clinical question regarding the effectiveness of training upper limb movements in gravity-reduced body orientations. By characterizing the kinematics of the trajectory and interjoint coordination in healthy elderly persons, a baseline can be established to which patient populations can be compared. Three possible outcomes can be hypothesized: (a) Participants may produce the same movement pattern regardless of changes in body orientation; (b) participants may produce a completely different movement pattern with respect to body orientation; and (c) some of the movement characteristics would remain consistent between the two orientations, whereas others would change.
Method

Participants

Nine healthy, right-hand-dominant women volunteered for this study. They ranged in age from 62 to 66 years ($M = 63.6$ years). The participants had no known history of neurological or orthopedic disorders. Before participation, they were fully informed of the nature and procedure of the project and gave their consent to be tested. Approval to conduct this study was granted by the Teachers College Institutional Review Board.

Task and Apparatus

The experimental task involved pointing to a target that was 2 cm in diameter in two different body orientations. In the sitting condition, participants performed the pointing movement within the sagittal plane. In the side-lying condition, they pointed in the horizontal plane. In both conditions, the participants’ hips and knees were placed in $90^\circ$ of flexion, and their trunks were supported in a neutral position by a high, straight-back chair or a side-lying plinth (see Figure 1). Participants were told to keep their backs in contact with the back of the chair or plinth. To ensure that this position was maintained, the experimenter made a visual inspection of trunk position before each trial. Pilot data revealed that participants had difficulty maintaining trunk alignment between trials when in the side-lying orientation. To prevent deviations in trunk position, the trunk was strapped to the plinth in the side-lying position. The target was placed 6.25 cm above shoulder height at a distance equal to 80% of arm’s length. Two videocameras (Panasonic 500sx) were used; one was positioned to obtain a sagittal view to record the pointing movement in the sitting position, and the other was positioned overhead to record the pointing movement in the side-lying position.

Procedure

In both test conditions, participants pointed with their right arm, and the start position was standardized between the two conditions. The shoulder was positioned in $0^\circ$ of flexion, elbow in $90^\circ$ of flexion, and the forearm and wrist in the neutral position. Spherical reflective markers were placed at the following locations for the collection of shoulder and elbow angular data and wrist trajectory data: hip (greater trochanter), C7, shoulder (acromion process), elbow (lateral epicondyle), wrist (ulna styloid), head of the third metacarpal joint, and the distal interphalangeal joint of the index finger. For each condition, the participant was given three practice trials, followed by eight test trials. A trial was deemed successful if the plane of the movement was maintained throughout the entire trial. The first five successful trials of each condition were used in the analysis. The order of conditions was counterbalanced across participants. For both conditions, participants pointed at a self-paced speed after the examiner said, “Go.” The participants were provided with the following instructions: “Point to the center of the target and keep your finger on the target until you hear the examiner say, ‘Return’” (– 3 sec).

Data Processing and Analysis

The markers were digitized at a rate of 60 Hz, using the Peak Motus 6.0 system. This system has been found to be

Figure 1. Experimental setup. a. Sitting condition. b. Side-lying condition. Filled circles indicate placement of reflective markers. In both conditions, the target was placed at a distance equal to 80% of arm’s length.

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accurate (±0.08°) and reliable (ICC > .99) for angular measurements (Scholz & Millford, 1993). To reduce noise in the data, the 2-dimensional digitized data were processed through a quintic spline digital filter with a low-pass cutoff frequency of 6 Hz for all participants except Participant 1. After data collection for Participant 1, the movement analysis system was updated. Consequently, this participant’s data were digitized with the Peak 5.0 system and filtered with a dual-pass Butterworth digital filter with a low-pass cutoff frequency of 6 Hz. No differences were noted in Participant 1’s data when compared with the others; thus, she was included in the analysis. Labview kinematic software was used to compute hand paths, velocities, and angle–angle plots of the pointing movements for all participants.

The following kinematic variables were used to evaluate movement of the hand: (a) linear peak velocity, (b) time to peak velocity, (c) movement time, and (d) percent time spent in acceleration [(time to peak velocity/movement time) x 100]. Movement onset was defined as the time when linear velocity exceeded a criterion value of 2 cm/s. Termination was defined as the time when the linear velocity fell to a value closest to the criterion value of 2 cm/s. In addition, a linearity ratio was calculated to quantify the straightness of the hand paths as follows: First, the shortest distance (a straight-line path) was determined by calculating the displacement of the wrist from the start to the end of the movement. Second, the actual distance the hand traveled was determined by summing the displacement of the wrist between each data point. Third, the ratio of these two values was defined as the linearity ratio (Quinn, Hamel, Flanagan, & Kaminski, 1997). A value of 1 would indicate a perfectly straight hand path. Values less than 1 would indicate a deviation from a straight-line path.

The following kinematic variables were used to evaluate the coordination between the shoulder and elbow joints: (a) angular peak velocity, (b) time to peak velocity, (c) elbow time to peak velocity relative to shoulder time to peak velocity (elbow – shoulder), (d) angular displacement of the shoulder and the elbow, and (e) scapula displacement. To determine scapula displacement, we first evaluated the contribution of the trunk to the movement. In all cases the trunk remained stationary (< 1° change in trunk angle). Because the trunk remained stable throughout the movement, we determined scapular motion by summing the displacement of the acromion marker between each data point. Although measuring scapular movement is a complex process requiring 3-dimensional analysis to capture scapular translation, elevation, and rotation fully (see Kaminski, Bock, & Gentile, 1995), we believed that this analysis would provide a rough estimate of the relative contribution of scapular motion to the pointing movement. Onset time of joint motion was defined as the time when joint angular velocity exceeded 5°/s. Termination was defined as the time when joint angular velocity fell to a value closest to the criterion value of 5°/s.

Mean, standard error of the mean, and coefficient of variation (SD/M) were calculated for all the kinematic variables. Paired t tests (2-tailed) comparing the group means of the same kinematic variables were performed to determine statistical significance (p < .05).

Results

Kinematics of the Hand

As can be seen from the representative participants depicted in Figures 2a and 2b, the path of the hand was not significantly influenced by body orientation. Hand paths were relatively straight under both conditions. Although some participants had a slightly curved hand path under the sitting condition (Figure 2b), linearity ratios across participants were not significantly different between the two conditions (side-lying position, M = .99, SEM = ±0.001; sitting position, M = .98, SEM = ±0.002), t(8) = 1.62, p = .14.

Additionally, as can be seen from Figures 2c and 2d, the shape of the tangential velocity profiles did not differ as a consequence of body orientation. The velocity profiles were smooth and approximately bell-shaped, with no differences noted in percent time spent in acceleration (M = 36.7% for both conditions across all participants). Despite these similarities, peak velocity was lower (side-lying, M = 51.1 cm/s, SEM = ±6.47; sitting, M = 63.6 cm/s, SEM = ±7.2), t(8) = -2.55, p = .03, and movement time was prolonged (side-lying, M = 1.5s, SEM = ±0.18; sitting, M = 1.3 s, SEM = ±0.18), t(8) = 3.66, p = .006, under the side-lying condition compared with the sitting condition.

Joint Kinematics

The relationship between shoulder and elbow displacement and the timing relationship between the shoulder and elbow joints were evaluated to determine differences related to changes in body position. As can be seen from the angle–angle plots of two representative participants depicted in Figures 3a and 3b, two distinct patterns emerged regardless of body orientation. As indicated in Figure 3a, some participants chose a pattern that was more

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4National Instruments Corporation, 11500 North Mapac Expressway, Austin, Texas 78759-3504.
Figure 2. Hand paths (a & b) and tangential velocity profiles (c & d) of two representative participants. Note. Side-lying condition (dashed); sitting condition (solid).

Figure 3. Angle–angle plots of the shoulder against the elbow of two representative participants. The shoulder is plotted on the x axis, and the elbow is plotted on the y axis. Note. Side-lying condition (dashed); sitting condition (solid).
simultaneous in nature, with shoulder flexion occurring slightly ahead of elbow extension, after which the joints moved concurrently. Other participants chose a pattern that was more sequential in nature (Figure 3b), with flexion of the elbow occurring first, followed by shoulder flexion and then shoulder flexion coupled with elbow extension later in the movement. Furthermore, in those participants who chose the more sequential pattern, the degree of elbow flexion differed with respect to body orientation, with less elbow flexion occurring in the early phases of the movement in the side-lying position. Despite these participant-related differences in movement patterns, the shoulder and elbow moved less under the side-lying condition (Figure 3a & 3b). To evaluate these differences more closely, total angular displacement of the joints was examined.  

Despite that the task required the participants to displace the hand the same distance in both conditions, angular displacement of the shoulder and elbow joints varied as a consequence of body position. Both the shoulder and elbow moved less under the side-lying condition as compared to the sitting position (Figure 4a) $t(8) = –4.43, p = .002$, $t(8) = –2.68, p = .02$, respectively. Given that the shoulder and elbow moved less under the side-lying condition and that total displacement of the hand remained consistent under the two conditions, scapular motion was assessed to determine its contribution to the overall movement of the hand. As can be seen in Figure 4b, tangential displacement of the scapula was greater in the side-lying condition, $t(8) = 6.05, p = .000$. Peak velocity of both the shoulder (side-lying, $M = 68°/s, SEM = ±8.3$; sitting, $M = 100°/s, SEM = ±12.6$) and the elbow (side-lying, $M = 34°/s, SEM = ±4.5$; sitting, $M = 61°/s, SEM = ±7.9$) were significantly affected by body orientation. The angular peak velocities of both the shoulder, $t(8) = –3.56, p = .007$, and the elbow, $t(8) = –4.53, p = .002$, were decreased under the side-lying condition.

**Temporal Coordination**

The temporal relationship between the shoulder and elbow varied as a consequence of body orientation as evidenced by the differences noted in shoulder and elbow time to peak velocity. Elbow time to peak velocity was evaluated relative to time to peak velocity of the shoulder. Regardless of body orientation, the shoulder peaked first under both conditions. However, in the side-lying condition, the shoulder reached its peak later relative to the shoulder in comparison to the sitting condition (side-lying, $M = 0.23$ s, $SEM = ±0.09$; sitting, $M = 0.15$ s, $SEM = ±0.08$), $t(8) = 2.52, p = .03$, indicating a modification in the temporal coupling between the joints.

**Discussion**

Regardless of changes in body orientation relative to gravity, participants produced straight hand paths and smooth, bell-shaped velocity profiles. However, they moved more slowly in the side-lying body orientation. Although the trajectories remained relatively invariant, the pattern of inter-joint coordination varied as a consequence of body orientation; the shoulder and elbow moved less within the side-lying position, whereas the scapula made a greater contribution to the overall movement. Additionally, the temporal coordination of the joints was modified as a consequence of body orientation. These results will be discussed in relation to movement similarities and differences, and their relevant clinical implications will be considered.

**Movement Similarities**

Participants produced relatively straight hand paths and similar velocity profiles under both conditions, indicating
that they planned equivalent trajectories. This finding is consistent with what has been shown previously regarding the invariance of trajectories during point-to-point arm movements under varying task conditions (Abend, Bizzi, & Morasso, 1982; Georgopoulos, 1986; Haggard, Hutchinson, & Stein, 1995; Kaminski & Gentile, 1986; Morasso, 1981; Soechting & Lacquaniti, 1981). However, our results contrast those of Papaxanthis et al. (1998), who found that movement direction relative to gravity altered the shape of the velocity profile. The disparity between the results may be explained by the fact that different tasks were used. Papaxanthis et al. had participants move the limb in a direction that either resisted gravity or resulted in gravity assisting the motion, whereas our task minimized the effect of gravity on the prime movers of the reaching movement (i.e., anterior deltoid and biceps). More importantly, in their study neither the arm nor the target was visible during the movement, whereas in ours both were visible. It has been well established that errors in pointing increase when vision is not available (Soechting & Flanders, 1989). Additionally, it has been shown that reaction time increases and the timing relationship between the eye and hand differ when vision is not available (van Donkelaar & Staub, 2000), indicating that pointing movements are performed differently with respect to the availability of vision. Perhaps the fact that our participants were able to use both kinesthetic and visual information during the movement allowed them to produce the trajectories without altering the acceleration and deceleration phases of the movement. Thus, the effect of movement direction relative to gravity may vary depending on other task constraints.

Movement Differences

Despite the similarities in the movements, our data support previous findings that suggest that movement kinematics are altered as a consequence of movement direction relative to gravity (Papaxanthis et al., 1998; Schiller et al., 1999). The results of our study indicate that participants moved slower within the side-lying orientation. Past evidence suggests that the trajectory of the hand during point-to-point arm movements does not depend on speed and that movement duration is free to vary (Georgopoulos, 1986; Hollerbach & Flash, 1982; Soechting & Lacquaniti, 1981). It is possible that our participants simply chose to move slower in the side-lying body position because of limited experience with pointing in this orientation. Alternatively, Lino and Bouisset (1994) found that an increase in upper body stability is associated with a decrease in maximum wrist velocity. Although the trunk and lower extremities were supported in both conditions, additional lateral support was provided to the body in the side-lying position. It could be argued that this additional support resulted in an increase in upper body stability, thus accounting for the decrease in peak velocity of the wrist and the subsequent prolonged movement duration associated with the side-lying orientation.

At the joint level, participant-specific differences in pointing strategies were noted, regardless of body orientation. Some participants began the movement with shoulder flexion, whereas others began with elbow flexion. These differences are consistent with what has been reported previously for pointing movements (van der Fits et al., 1998) and may have been the result of individual participants attempting to match their morphology (i.e., muscle mass, limb segment lengths) with the demands of the task.

Furthermore, despite these participant-specific differences, displacement of the shoulder, elbow, and scapula differed as a consequence of body orientation, indicating that a modification in the pattern of joint movement occurred. In addition, the timing relationships between the shoulder and elbow varied as a consequence of changing body orientation, indicating a modification in the temporal relationship between these two joints. It is conceivable that strapping the trunk in the side-lying position may have enhanced trunk stability, contributing to the differences seen at the joint level; however, this seems unlikely given that no differences were seen in movement of the trunk between the two orientations. The kinematic variations seen at the joint level are likely the result of the differences in the underlying dynamics that occur when a change in body orientation relative to gravity is imposed. The fact that changing body orientation relative to gravity resulted in different joint kinematics is consistent with the notion that there is not a one-to-one correspondence with the goal of the movement (getting the hand to the target) and the movement pattern (shoulder and elbow coordination) used to achieve the goal (Abbs & Cole, 1987; Gentile, 2000; Green, 1972).

Clinical Implications

The interaction among the person, task, and environment is a core concern of the occupational therapy profession (Mosey, 1974; Peloquin, 1994; Reilly, 1962). Contemporary treatment models aimed at remediating motor behavior have reaffirmed the importance of this interaction in the evaluation and treatment of persons with neurological impairments (Carr & Shepherd, 2000; Gillen, 1998, 2001; Haugen & Mathiowetz, 1995; Mathiowetz & Haugen, 1994; Sabari, 1995). According to Haugen and Mathiowetz (1995), the context in which movement takes place is a variable that must be considered during the treatment process. The results of our study support this notion. The findings indicate that point-to-point arm movements
made in side-lying differ from those made in sitting, particularly at the joint level, and illustrate that movement organization is sensitive to this contextual difference. However, whether these differences will be seen in patient populations and whether they will affect transfer of training is not known.

Evidence suggests that the trajectory of the end-point is what is being specified during point-to-point arm movements (Won & Hogan, 1995). Given this information coupled with the finding that participants in this study produced similar trajectories in the two body orientations, it can be speculated that training of the upper limb in gravity-reduced body orientations may be of benefit if endpoint specification is what patients need to relearn. However, if deficits in motor performance are due to impairments in interjoint coordination, a different conclusion may be reached. For example, deficits in motor performance after a stroke may be the result of impaired interjoint coordination rather than difficulty with planning the trajectory of the end-point (Beers, Dewald, & Rymer, 1999, 2000; Cirstea & Levin, 2000; Levin, 1996). After stroke, patients have been noted to be able to reach into various areas of the workspace; however, they move their shoulder and elbow joints less during point-to-point arm movements (Levin, 1996). Given that the participants in this study used a different pattern of interjoint coordination to transport the hand in space in the different body positions, it raises the question about what affect these differences would have on transfer of training between these two orientations.

Conclusion

The clinical question regarding the efficacy of retraining upper limb movements in various body orientations remains an open and important inquiry. Given the current trend toward evidence-based practice, it has become increasingly important to provide empirical support for what is considered common clinical practice in order to validate occupational therapy services to consumers at large (Holm, 2000; Tickle-Degnen, 2000). By providing information on reducing the effects of gravity through a change in body orientation on a multijoint arm movement, this study provides a first step in determining whether training of upper limb movement in gravity-reduced body orientations is a sound clinical practice. However, because the participants in this study were healthy, limited conclusions can be drawn. These findings need to be extended to clinical populations, and the issue of transfer of training needs to be explored in order to determine whether this common therapy practice is a valid one.

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