The effect of arm movement on the biomechanics of standing up *

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Abstract

The role of the arms and their relationship to the lower limbs in the action of standing up was evaluated. Six subjects were videotaped from the side as they stood up with their feet on a force plate. Subjects stood up, under three arm-movement conditions: with arms moving naturally, with arm movement restricted by holding a rod and with arm movement augmented by the requirement to point. The results indicated that arm movement occurs naturally during standing up. There was a close temporal synchrony between the onset of arm flexion and lower limb extension in both the preferred and the restricted conditions. When arm movement was augmented, however, this synchrony was not apparent. Augmenting arm movement increased the linear momentum of the body centre of gravity and force generation in the lower limbs. It appears, therefore, that arm movement does play a part in potentiating horizontal and vertical propulsion of the total body into the upright position. Clinical implications arising from this study are discussed.

1. Introduction

A major challenge for researchers in the field of human movement study is to describe how the dynamic interactions between linked segments is

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organised to produce effective and efficient motor behaviour. In particular, little is known about the segmental interactions between the upper limbs, trunk and lower limbs in actions which involve transporting the total body over a fixed foot (e.g., walking, running, jumping and standing up). Researchers investigating these movements, with a few exceptions (e.g., Muzii et al., 1984; Hinrichs, 1987), have tended to concentrate on the lower limbs. Recently, however, several investigators have pointed out the need to explore further the role of the trunk and upper limbs in actions involving the total body (Hinrichs, 1990; Winter et al., 1990).

The purpose of the present study was to examine intersegmental relationships between upper and lower limbs and trunk during standing up, a multijoint action in which the segmental rotations transport the total body from one base of support to another, that is, from the thighs to the feet. The major question addressed was whether or not arm movement plays an integral part in standing up by aiding translation and propulsion of the total body. Beyond contributing to understanding control processes in a complex movement, this information would have implications for clinical practice in rehabilitation. Standing up is an essential prerequisite for ambulation and, thus, for the independence of individuals with movement dysfunction. Insight into the movement coordination used in standing up may permit evaluation of current approaches and guide the development of more effective strategies in rehabilitation practice.

Standing up is commonly achieved with the upper extremities free and available to assist propulsion by, for example, pushing on the arms of the chair or by swinging forward. The upper extremities may also be functionally restricted, such as when standing up while holding onto a glass or tray. In other instances, the upper limb may be required to move away from the body during standing up, as in standing up while reaching out to shake hands. Similar to locomotor and jumping actions, in standing up the arms may assist in maintaining balance. The upper extremities may also influence the mechanical interaction between the horizontal and vertical movements of the total body over the fixed feet, playing a significant role not only in balancing the individual, but also in facilitating lower limb propulsion.

Since there are no studies of standing up that have specifically investigated arm movement, it is not known whether the arms are functionally linked into the lower limb and trunk segmental system when individuals stand up and what the nature of such a linkage may be. In actions similar to standing up, movement of the upper extremities is not an incidental
aspect but an integral part of these actions. For example, during walking arm swing results from muscle contraction, not simply passive forces (e.g., Fernandez-Ballesteros et al., 1965), and may serve to reduce the vertical excursion of the total center of body mass thus reducing energy cost (e.g., Murray et al., 1967; Hinrichs et al., 1987).

There is some evidence that active arm flexion naturally accompanies standing up and that the extent of this arm movement is variable (Kelley et al., 1976; Jones and Hanson, 1961; Fleckenstein et al., 1988). Some observations suggest that the upper limbs are utilized in standing up when speed is a factor (Jones and Hanson, 1961), and when the angle of shank segment is restricted (Fleckenstein et al., 1988; Stevens et al., 1989).

Jones and Hanson (1961) observed that the fundamental difference between subjects moving at fast and slow speeds was the way in which they used their arms. They reported that subjects in the fast group seemed to throw their arms forward and upward suggesting that these subjects altered both the position of the body centre of gravity (COG) and moment of inertia. In contrast, subjects in the slow group used their arms very little.

Although Fleckenstein and colleagues (1988) reported that arm movement was pronounced when shank position was restricted to the vertical position or greater, they did not report the details of upper extremity movement. Stevens and colleagues (1989), however, presented data which showed a high level of activity in upper trapezius muscle, a trunk muscle which inserts into the shoulder region, when the shank was restricted to a vertical position and subjects were not permitted to move their feet back. It is likely that increased activity in the upper trapezius reflected a forward and upward movement of the arms in order to increase horizontal and vertical propulsion of the body mass. This strategy would be required to compensate for the relatively forward position of the feet.

As an extension of the available research findings, it was hypothesised that the naturally occurring arm movement during standing up is utilised and timed to potentiate lower limb extensor force. Furthermore, given the functional linkage between upper and lower limbs and the trunk, it was predicted that arm movement affects horizontal and vertical propulsion of the total body. In the present study, these hypotheses were examined by varying the extent of arm movement during standing up in three ways. Subjects stood up with arm movement: (a) occurring naturally (preferred condition); (b) functionally restricted (restricted condition); and (c) augmented (pointing condition). As would be expected, subjects had no difficulty standing up while pointing to a target or when arm movement was
restricted. Such variations in arm movement did, however, have an effect on the dynamics of standing up. Augmenting or restricting arm movement significantly altered both the linear momentum of the body’s COG and force production in the lower limbs. There was some evidence that work done by the lower limb muscles, and, therefore, the energy expended, was greater when arm movement was restricted.

2. Methods

2.1. Subjects

Six male subjects aged between 20 and 30 years ($M = 24$ yrs, $SD = 2.3$), of average weight ($M = 71.2$ kg, $SD = 9.0$) and height ($M = 1.75$ m, $SD = 0.1$) and with no known musculoskeletal or neurological dysfunction participated in the study. Subjects were informed about the nature and purpose of the study, and gave their written consent.

2.2. Apparatus

Subjects sat on a height-adjustable seat (comprising a flat sitting surface and without arms) with their ischial tuberosities positioned directly over a pressure-sensitive switch strapped on to the front of the seat and attached to a light (DC). Deactivation of the light signalled a loss of contact with the seat. The sensitivity of the switch had been determined as 100 g or 1 N.

Seven low-inertia light-reflecting markers were placed on the subject’s skin on the right side of the body over the following anatomical landmarks: the lateral epicondyle of the humerus; lateral aspect of the glenohumeral joint; greater trochanter; head of fibula; lateral malleolus; heel and fifth metatarsal head. The markers defined a five-segment model made up of upper arm, trunk, thigh, shank and foot. Distances between the markers defining the segment lengths were recorded in cm for each subject, together with other relevant anthropometric data.

Subjects were videotaped as they stood up using a video camera (National WVO-F10 CCD) placed at right-angles to the sagittal plane of motion. The video camera has a fixed sampling rate of 25 Hz and a shutter speed of 1/1000 sec. Fourier analysis indicated that there was no significant information in frequency components above 2 Hz.
Ground reaction force data were collected simultaneously with the video data as subjects stood up with both feet on a Kistler Type 9281 (40 × 60 cm) force plate using a Data Translator DT2801 analog-to-digital converter card installed in a GCS, AT computer. The six output channels of the force platform (4 vertical force plus 2 horizontal signals) were sampled at 200 Hz. In order to synchronize the video and force plate (FP) data, a specially-designed light-emitting diode (LED) timing device was placed in view of the camera and connected to the AT computer. Each time the computer sampled the force platform data, a different combination of lights of the LED timing box was illuminated. Although the force platform data were sampled eight times more frequently than the camera, the camera's fast shutter speed ensured that every video frame had a unique force platform sample associated with it. During digitizing, as each frame is advanced, the timing box numbers change in increments of eight. These numbers were recorded for each frame. At the data analysis stage, the timing box numbers were transferred to computer files so that subsequent kinetic analysis and output would be matched frame-by-frame to the kinematic analysis and output.

2.3. Procedure

The subject's starting position was standardized. The trunk was positioned vertically using a template comprising wooden arms set at the angle of 90 deg and incorporating a spirit level. Seat height was adjusted to lower leg length measured from the head of the fibula to the floor with the subject barefoot in standing. The seat was positioned in relation to the force plate so that the subject's heels were placed in a box marked on its surface. This resulted in a dorsiflexed position at the ankle.

Arm movement during standing up was varied in three ways. In the preferred arm-movement condition subjects started with hands resting between their thighs to prevent the hands from pushing down on the thighs. Subjects were instructed to stand up naturally while looking straight ahead at a target circle placed at eye level, measured in sitting, and approximately 6 m in front of subjects. In the pointing condition, hands again rested between the thighs and subjects were required to point to the target with the right arm while standing up. For the restricted condition, subjects were asked to hold onto a wooden rod with both hands and with the forearms at 90 deg to stand up while holding the elbows into the side of the trunk.
Subjects performed four practice movements prior to data collection for all arm-movement conditions. For data collection, each subject performed six trials (plus 2 additional trials) under each of the three conditions. Data were collected on different days for different conditions to minimise carryover between conditions. The order in which each subject performed the conditions was randomised.

Subjects were instructed to stand up at their normal preferred speed, described to them as a natural comfortable speed. Data from a previous study (Carr, 1987) indicated that when speed was defined in this way 94.5% of all trials fell within 1.5 SD of the mean total movement time. Any trials that did not meet this criterion were eliminated at the data analysis stage. In no instance were there less than six trials per subject per experimental condition.

Coordinate data (X, Y) were extracted from the videotape using the digitization system described by Abraham (1987). The digitizing procedure was controlled by a computer routine running on the microcomputer. This routine is part of a computer software package (Smith, 1988) which is designed to analyse human movement.

2.4. Analysis

The analysis involved filtering the input coordinate data using a low-pass, critically-damped digital filter (4th order, Butterworth-type). The software package was used to determine segmental and total body kinematics, joint moments of force and mechanical powers of hip, knee and ankle as well as total support moment of force. As shown in Fig. 1, four segment angles (upper arm, trunk, thigh, shank) were calculated as absolute angles in space in a five-segment four-joint system. For ease of description throughout this paper, the terms shoulder, hip, knee and ankle are used to represent the absolute angles. Data from the force plate related to ground reaction forces together with the coordinate data enabled calculation of net joint moments of force and overall support moment of force. For the calculation of support moment of force, the following algebraic summation was used: \( M_s = M_a + M_k + M_h \) where \( M_a \), \( M_k \) and \( M_h \) are respectively the moments at ankle, knee and hip (Winter, 1984). Mechanical power was calculated as the product of the joint moment of force and joint angular velocity.

Three events provided reference points: movement onset, thighs-off and movement end. Movement onset was defined as the time at which a
Fig. 1. The five-linked rigid segment model used in the kinematic analysis showing segments and absolute or segment angles. The terms, shoulder, hip, knee and ankle are used in the text for ease of description to represent upper arm, trunk, thigh and shank segmental rotations. All segments are defined as +ve in the counterclockwise direction from the horizontal. (Adapted from Winter, 1987.)

Note: $\phi_{ua} =$ upper arm (shoulder); $\phi_{tr} =$ trunk (hip); $\phi_{th} =$ thigh (knee); $\phi_{sh} =$ shank (ankle).

decrease of 10 N from the baseline in vertical (Z) force was apparent. The decrease in vertical force is probably related to an early lifting of the thighs when the hip flexors initially contract to move the trunk forward. The second event, thighs-off was the time at which contact with the seat-switch was broken. This was recorded on the video by onset of the light signal. The third event, movement end, was defined as the time at which the horizontal velocity of hip marker equalled or was less than 0.10 m/s.

Basic link-segment equations utilizing the kinematics, anthropometrics and reaction forces (Bresler and Frankel, 1950; Winter, 1979) gave the joint moments of force and powers at the three segment angles. Kinetic data were normalized by dividing the moment of force and power by each subject's body mass.

The analysis of the X, Y coordinate and force platform data resulted in real-time kinematic and kinetic data files. Movement duration was analysed in terms of a pre-extension phase (movement onset to thighs-off) and an extension phase (thighs-off to movement end). In addition, timing measures were derived for onset of shoulder flexion and lower limb extension or
thighs-off. So as to compare duration and timing measures, across subjects and conditions, these scores were expressed as a percent of total stand-up time or as a percent of the extension phase.

The dependent variables were amplitude of arm and trunk flexion; onset times of arm flexion and lower limb extension; horizontal and vertical linear momentum of the body center of gravity (COG); peak moment of force at hip, at knee and at ankle; peak support moment and the duration of maximum support moment (defined as the percent of the extension phase support moment equalled or was greater than three times the body mass). Statistical evaluation of data involved an analysis of variance for repeated measure followed by Scheffe test for individual comparisons. The 0.05 level of significance was used for all tests. For graphic representations of lower limb joint displacements, moments of force and mechanical powers, all output data were time-normalized to 100% from thighs-off to movement end.

3. Results

3.1. Arm and trunk movement

Amplitude of arm flexion

In the preferred condition, arm flexion (forward movement of the upper arm at the shoulder joint) occurred naturally during standing up. Alterations in the amplitude and duration of this movement were observed when subjects pointed to the target or had arm movement restricted, confirming the effectiveness of the experimental manipulation. Pointing while standing up increased flexion at the shoulder compared with natural arm use. Restricting arm movement by requiring subjects to hold a rod into the sides of the trunk while standing up decreased the movement (Table 1). Analysis of variance indicated significant effect of condition \((F(2,10) = 100.27, p = 0.0001)\). As would be expected, arm flexion was significantly greater under the pointing condition than under both the preferred \((F = 63.88, p < 0.05)\) and restricted conditions \((F = 85.02, p < 0.05)\). There was no evidence of a difference between the mean amplitude of shoulder flexion under the preferred and restricted conditions.

Amplitude of trunk flexion

Since the extent of arm movement may have affected the extent to which the trunk flexed forward at the hips, the amplitude of trunk flexion was
Table 1

Mean amplitude (deg) of arm and trunk flexion under the three arm-movement conditions

<table>
<thead>
<tr>
<th>Arm-movement condition</th>
<th>Amplitude of arm flexion</th>
<th>Amplitude of trunk flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preferred</td>
<td>34.2 (13.2)</td>
<td>37.7 (7.7)</td>
</tr>
<tr>
<td>Restricted</td>
<td>25.9 (6.1)</td>
<td>31.9 (6.2)</td>
</tr>
<tr>
<td>Pointing</td>
<td>88.7 (11.3)</td>
<td>31.8 (3.6)</td>
</tr>
</tbody>
</table>

Note: SDs are in parentheses.

examined (Table 1). There was no significant difference between conditions ($F(2,10) = 3.41, \ p > 0.05$).

Comparison between onset times of arm flexion and lower limb extension

Mean onset times of arm flexion and of lower limb extension (defined as thighs-off), expressed as a percent of total stand-up time, occurred very close in time in the preferred and restricted conditions suggesting a timing relationship between the two events (Table 2). The onsets of arm flexion and lower limb extension were examined trial by trial and were defined as simultaneous if they occurred within 40 ms of each other. The two events occurred simultaneously in 81% of trials under the preferred arm-movement condition and 69% of trials in the restricted condition. Under the pointing condition, however, the two events occurred simultaneously in only 8% of trials. The percent of trials in which the onsets of shoulder

Table 2

Mean onset time of arm flexion and lower limb extension under three arm-movement conditions

<table>
<thead>
<tr>
<th>Arm-movement condition</th>
<th>Onset times</th>
<th>Upper arm flexion</th>
<th>Lower limb extension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>% a</td>
<td>AT b (msec)</td>
</tr>
<tr>
<td>Preferred</td>
<td></td>
<td>47.3 (3.8)</td>
<td>779 (101)</td>
</tr>
<tr>
<td>Restricted</td>
<td></td>
<td>49.0 (3.5)</td>
<td>758 (101)</td>
</tr>
<tr>
<td>Pointing</td>
<td></td>
<td>75.8 (11.5)</td>
<td>389 (203)</td>
</tr>
</tbody>
</table>

Note: SDs are in parentheses.

a Expressed as a percent of total stand-up time.
b AT = actual time from movement onset.
Table 3
Mean peak horizontal and vertical linear momentum of the body’s center of gravity (kg·m/s) under the three arm conditions

<table>
<thead>
<tr>
<th>Arm-movement condition</th>
<th>Horizontal momentum</th>
<th>Vertical momentum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preferred</td>
<td>29.8 (6.4)</td>
<td>44.1 (10.6)</td>
</tr>
<tr>
<td>Restricted</td>
<td>28.5 (7.2)</td>
<td>43.3 (12.9)</td>
</tr>
<tr>
<td>Pointing</td>
<td>32.8 (6.2)</td>
<td>49.7 (13.0)</td>
</tr>
</tbody>
</table>

Note: SDs are in parentheses.

Flexion and lower limb extension occurred simultaneously was significantly greater under preferred and restricted conditions than under the pointing condition (PREF vs. POINT: $F = 16.23$; REST vs. POINT: $F = 11.61$; both $p < 0.05$). There was no significant difference between the restricted and preferred conditions.

3.2. Momentum of body COG

Presented in Table 3 are the means for peak horizontal and vertical momentum of the body’s COG. Analysis of variance indicated significant differences between arm-movement conditions (horizontal: $F(2,10) = 6.59$, $p = 0.01$; vertical: $F(2,10) = 5.62$, $p = 0.02$). When pointing was imposed on standing up, both the horizontal ($F = 6.27$, $p < 0.05$) and vertical ($F = 4.71$, $p < 0.05$) momentum of the total body were significantly greater than when the arms were restricted.

3.3. Lower limb extension

Joint displacement

The lower limb segments extended throughout the period between thighs-off and movement’s end. As shown in the ensemble-averaged graphs of lower limb joint displacements (Fig. 2), segmental extension at hip and knee was not complete at movement’s end under the restricted and pointing conditions. The restricted arm condition resulted in high variabil-
Fig. 2. Ensemble-averages of angular displacements during the extension phase. Graphs show mean displacements for the six trials on six subjects under the three arm-movement conditions. Coefficients of variation (CV) are mean standard deviations (outer lines) as a percent of the mean (middle line). Angular displacements are from flexion to extension. Cycle at 0% = thighs-off, at 100% = movement end.

It is notable that, in the restricted condition, the shank segment was still moving forward at the ankle at the start of the extension phase and continued to dorsiflex during 28% of this phase. The fact that the shank continued to move forward on the fixed foot in the early part of the extension phase, and that the horizontal momentum was less suggest that
Fig. 3. Ensemble-averaged profiles of normalized joint moments of force during the extension phase. Graphs show mean moments for the six trials on six subjects under the three arm-movement conditions. Coefficients of variation (CV) are mean standard deviations (outer lines) as a percent of the mean (middle line). Hip and ankle extensor moments are indicated by −ve values; knee extensor moments by +ve values. Cycle at 0% = thighs-off, at 100% = movement end.

Peaks joint moment of force

In Fig. 3, ensemble-averaged graphs illustrate the overall pattern of moments of force at hip, knee and ankle for the three arm-movement conditions. When standing up naturally (preferred), extensor moments were evident at all joints from thighs-off until near movement's end when moments changed to flexor at hip and knee. Basically, the same pattern was seen under the restricted condition except the shift to flexor moments

subjects were using this strategy to get the COG sufficiently forward over the feet in order to ascend into standing.
Table 4
Mean peak extensor moment of force (N.m/kg) at hip, knee and ankle during the extension phase under the three arm-movement conditions

<table>
<thead>
<tr>
<th>Arm-movement condition</th>
<th>Peak moments of force (N.m/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hip</td>
</tr>
<tr>
<td>Preferred</td>
<td>3.05</td>
</tr>
<tr>
<td></td>
<td>(0.4)</td>
</tr>
<tr>
<td>Restricted</td>
<td>2.90</td>
</tr>
<tr>
<td></td>
<td>(0.4)</td>
</tr>
<tr>
<td>Pointing</td>
<td>3.15</td>
</tr>
<tr>
<td></td>
<td>(0.4)</td>
</tr>
</tbody>
</table>

Note: SDs are in parentheses.

did not occur. In both the preferred and restricted conditions, profiles for joint moments of force were smooth and continuous. However, when subjects were required to point while standing up, discontinuities were observed indicating corrections in extensor force production.

Peak moments of force for hip and ankle occurred at thighs-off under all arm-movement conditions. Knee moments peaked later, at about 10% to 20% of the extension phase, occurring earliest in the pointing condition.

Differences in peak extensor moments (Table 4) were evaluated using a 3 (joint: hip, knee, ankle) × 3 (condition: PREF, REST, POINT) analysis of variance. Main effect of joint was significant (F(2,10) = 37.53, p = 0.01) whereas, condition was not (F(2,10) = 0.30, p > 0.05). However, the interaction of joint × arm condition was significant (F(4,20) = 5.00, p = 0.01). Mean peak moments of force at the hip were consistently higher than at knee or ankle with no evidence of differences across arm-movement conditions. Under the preferred and restricted conditions, peak moments at knee and ankle appeared comparable. Under pointing, the pattern differed; peak moment was lower at the knee and higher at the ankle than under the other two conditions.

Support moment of force
There is evidence in both the stance phase of walking (Winter, 1980) and in standing up (Shepherd, 1991) that, in spite of variations evident at individual joints, moments at the three lower limb joints combine into a consistent net extensor moment, called by Winter (1980) a support moment. Shepherd (1991) reported an overall support moment of force 4.7 times body weight during standing up. In the present study, peak support moment of similar magnitude (Table 5) occurred around thighs-off but was
Table 5
Mean peak support moment and duration of maximum support moment under three arm-movement conditions

<table>
<thead>
<tr>
<th>Arm-movement condition</th>
<th>Peak support moment</th>
<th>Duration maximum support moment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>%&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Preferred</td>
<td>4.8</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td>(0.4)</td>
<td>(2.5)</td>
</tr>
<tr>
<td>Restricted</td>
<td>4.7</td>
<td>16.8</td>
</tr>
<tr>
<td></td>
<td>(0.5)</td>
<td>(2.7)</td>
</tr>
<tr>
<td>Pointing</td>
<td>4.9</td>
<td>15.8</td>
</tr>
<tr>
<td></td>
<td>(0.3)</td>
<td>(1.6)</td>
</tr>
</tbody>
</table>

Note: SDs are in parentheses.
<sup>a</sup> Percentage of the extension phase in which support moment = or > 3 times body mass.
<sup>b</sup> AT – Actual time in msec.

significantly greater under pointing than under the restricted condition ($F = 5.68, p < 0.05$).

The duration of maximum support moment, defined as a percentage of the extension phase that support moment equalled or exceeded three times body weight, is shown for each of the three conditions in Table 5. Analysis of variance indicated differences between conditions ($F(2,10) = 4.80, p = 0.03$) with a significantly briefer duration of maximum support moment for the preferred pattern of arm use compared to the restricted condition ($F = 4.61, p < 0.05$). The production of maximum force over a longer percent of the extension phase is not due to the duration of the extension phase for, as shown in Table 5, actual time of maximum support follows the same pattern (preferred briefer than restricted).

Joint powers

Ensemble averages of joint powers are shown in Fig. 4. Powers peaked in the order of hip, knee and ankle in all three conditions. As would be expected, power was generated at the three lower limb joints for a large percent of the extension phase. However, the shape of the power curve at the knee was different when the arms were restricted compared with the other two conditions. The pattern at the knee together with the power generation over 100% of the extension phase and the relatively higher peak value of power over the phase suggest that more work was being done at the knee over a longer period of time when the arms were restricted.
Fig. 4. Ensemble-averages of normalized joint powers during the extension phase. Graphs show mean powers for the six trials on six subjects under the three arm-movement conditions. Coefficients of variation (CV) are mean standard deviations (outer lines) as a percent of the mean (middle line). Power generation is indicated by +ve values; absorption by −ve values. Cycle at 0% = thighs-off, at 100% = movement end.

4. Discussion

Arm movement, i.e., forward flexion at the shoulder joint, happened naturally during standing up when subjects were instructed to carry out the movement in their ‘preferred’ manner. The onset of extension of the lower limbs, resulting in the thighs lifting off the stool, was coincident with the onset of arm flexion indicating a strong coordinative coupling of upper and lower limbs.
The temporal linkage between the onset of arm flexion and lower limb extension suggests that arm movement contributes to the vertical propulsion required to accelerate the body into the standing position. Hinrichs et al. (1987) have pointed out the dilemma in considering the arms as capable of propelling the body forward and upward in actions taking place over a fixed foot, since, as they say, the arms are not in contact with the ground. However, in standing up, as the arms start to accelerate upward at thighs-off, a net upward force is being exerted by the vertical movement of the body resulting from lower limb extension. The addition of the arm acceleration to the lower limb extension would create a larger downward force exerted on the ground than would occur without arm movement, as reported by Hinrichs and colleagues in running (Hinrichs et al., 1987). It is likely, therefore, that the timing of the application of the vertical ground reaction force in relation to the onset of acceleration of arm flexion in standing up would add to the impulse from the ground. This proposal was supported by the finding of a shorter duration maximal support moment.

Acceleration of the arms upward has been implicated in potentiating the vertical jump, which shares some common movement patterns with standing up, by raising the body COG to the highest possible point prior to take-off (Payne et al., 1968). Arm movement has also been found to increase the height reached by the body COG when children jump to reach for a target in contrast to when they jump as high as they could without specific instruction regarding arm movement (Poe, 1976).

An attempt was made in the present study to restrict arm movement during standing up using a procedure similar to that found in everyday functional tasks. Subjects were instructed to keep the upper arms along side the trunk and forearms at right angles to the trunk while holding onto a rod with both hands (similar to standing up while holding a tea tray). This procedure differed from that used in other recent studies in which subjects were required to hold the arms across the chest and not to bring them forward while standing up (e.g., Pai and Rogers, 1990; Jeng et al., 1990; Schenkman et al., 1990). In the present study, the restricted condition limited (but did not preclude) the extent of arm displacement. Apparently, forward movement of the arms is a potent concomitant or consequence of lower limb movement during standing up.

Although the natural linkage between upper and lower limbs was also evident in the restricted condition, there were some differences in the movement parameters associated with force propulsion. As seen in the preferred condition, onsets of arm flexion and lower limb extension were
tightly coupled in time when arm movement was restricted. There were many other similarities in movement organization under the preferred and restricted conditions: horizontal and vertical momentum of body COG; profiles for moments of force at hip, knee and ankle. These same outcomes for the preferred and restricted conditions were achieved by different means to compensate for loss of propulsive force due to less arm movement: lower support moment was compensated by longer duration of both maximum support moment and work at the knee.

A different coordinative pattern was seen when arm movement was augmented by the addition of pointing. In this condition, the upper limbs were disengaged from the lower limbs as evidenced by the lack of temporal coupling. Gentile (1987) has suggested that the upper limbs and hands have in general ‘two modes of operation’ (p. 111). They are either yoked to the postural system (for body stability and transport) or disengaged for interacting with objects. The evidence from the present study supports this view, showing that, in standing up, the freely moving arms aid in the translation of the total body from one base of support, the thighs, to another, the feet. When one arm is required to point to a target, however, the lack of a close timing relationship between the onsets of arm movement and lower limb extension seems to provide evidence that the arm is disengaged from the postural system under this condition. Nevertheless, the pointing movement still had an augmenting effect upon the generation of propulsive extensor force.

An interesting clinical implication for stroke rehabilitation arose from this study. It is common practice to have patients hold the affected arm in front of the body with the intact arm as described by Bobath (1990) and Davies (1985). Holding the affected arm in this way restricts natural arm use. The results of this study suggest that restricting arm movement may interfere with natural momentum of the movement and increase the time in which a high level of extensor force has to be produced by lower limb muscles.

Patients who have difficulty standing up due to lower limb muscle weakness, such as following total hip replacement and stroke, typically use one of two strategies to assist them. One strategy is to push down with the hands on the seat which assists lower limb extension until the force requirements are sufficiently reduced at hip and knee for the weak muscles (Butler et al., 1991). The other strategy is to swing the arms forward to assist horizontal and vertical propulsion of the body mass. Although these two strategies enable the person to stand up, they do not permit the
individual to perform the action flexibly under different task and environmental conditions. Consideration should be given in rehabilitation to strengthening the lower limb extensors for the action by having patients practise initially from a higher than normal seat which has been shown to reduce the muscle force requirement (e.g., Burdett et al., 1985; Rodosky et al., 1989). As the muscles become stronger and the segments better coordinated the seat height can be progressively reduced. This provides a form of progressive resistance exercise.

In conclusion, the evidence from this study increases our understanding of the dynamic relationship between upper and lower limbs in the action of sit-to-stand. The results showing a temporal linkage between the onsets of shoulder flexion and lower limb extension and the effect of the extent of arm movement on force production in the lower limbs suggest that the arms play a part in potentiating the horizontal and vertical propulsion of the total body. Furthermore, the findings provide additional evidence that movement of the upper extremities is not an incidental aspect of this action which involves movement over a fixed foot but an integral part of it as has been suggested in walking (e.g., Elftman, 1939; Murray et al., 1967; Hinrichs and Cavanagh, 1981), running (e.g., Hinrichs et al., 1987; Hinrichs, 1987) and jumping (e.g., Hay et al., 1978).

References


