Biomechanical Perspective on Effect of Angle in Arm Swing Movement on Vertical Ground Reaction Force for Gait Improvement

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The topic of research interest

Biomechanics

Gait analysis

Healthcare system
Introduction

Advances in medicine have led to an aging population in many developed countries[1].

Life expectancy and healthy life expectancy diverge.

Closing this gap is a societal challenge.

Walking exercise is attracting attention as a way to extend healthy life expectancy.

Introduction

Clinically known effects of arm swing during gait

Increased stride length\(^2\), Increased walking speed\(^3\) etc…

Problem

Depending on the individual's gait, modifying the arm swing movement may not result in an effective walking motion.

\[2\] S. Inoue and K. Saitou, “Effects of upper limb movement on walking motion during walking- As an aid to fall prevention-,”

\[3\] T. Siragy, C. Mezher, A. Hill and J. Nantel, “Active arm swing and asymmetric walking leads to increased variability in trunk kinematics in young adults,”
Research objective

To biomechanically elucidate the coupled process of arm swing and lower limb movement

Once the objective is achieved, the characteristics of an individual's gait can be explained by identifying the couple between movements.

Advantage

Contribution to health promotion by presenting gait improvement methods tailored to the gait often he individual.
Paper objective

To experimentally clarify how the bimodality of vertical ground reaction force changes with arm swing and to clarify mechanically what kind of coupling caused this change.
Experimental method

The purpose of this experiment was to measure the mechanical parameters and vertical ground reaction forces of each segment during walking.

Experimental equipment

- Force plate: 3 units
- Motion capture camera: 12 units
- Reflective marker: 41 pieces

Number of volunteers: 4 males (age: 22.5 ± 0.5 [years], height: 1.70 ± 0.03 [m], weight: 66 ± 2 [kg])

Number of attempts: 5 times

Gait conditions

- Without arm swing
- Naturally arm swing
- Backward arm swing
- Large backward arm swing
- Forward arm swing
- Large forward arm swing

Measurement section

- Steps 1~4
- Steps 5~7
- After the 8th step
Using software ~AnyBody~

Many parameters were obtained using AnyBody (AnyBody Technology Co.).

Motion Analysis Software by Musculoskeletal Modeling

Analyzable parameters

- Angle of body part
- Joint moment
- Muscle activity amount
  etc…
Featured parameters

Vertical ground reaction force values and pelvic lateral tilt angles were the focus of this study.

**Vertical ground reaction force**

The change in segment due to a change in gait can be known from a single parameter. In healthy walking, vertical ground reaction force values are bimodal, and there is a close relationship between walking motion and bimodal vertical ground reaction force values. For example, changes in walking speed and stride length cause bimodal changes in vertical ground reaction forces.

**Reason for a focus:**
We thought it was an important part for transmitting changes in the upper body caused by arm swing to the lower limbs.

**Lateral pelvic tilt angle**

**Reason for a focus:**
We thought it was an important part for transmitting changes in the upper body caused by arm swing to the lower limbs.
Result ~vertical ground reaction force~

Volunteer A walks starting from the waist.

Volunteer D walks with feet as starting points.

Fig 2. Comparison of vertical ground reaction force values for each gait condition for volunteer A during the stance phase.

The graph on the left shows the results for volunteer A, who showed a different trend from the other volunteers.

The graph on the right is representative of volunteer B to D who showed similar trends and is the result of volunteer D.

Results and discussion will focus on the leg-priority walking style seen in many volunteers.
Table I. BIMODAL AVERAGED VERTICAL GROUND REACTION FORCE VALUES FOR EACH GAIT CONDITION DURING THE STANCE PHASE. VALUES IN BOXES ARE INITIAL PEAK/VALLEY/LATE PEAK.

<table>
<thead>
<tr>
<th>Gait conditions</th>
<th>Volunteer A</th>
<th>Volunteer B</th>
<th>Volunteer C</th>
<th>Volunteer D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without arm swing</td>
<td>688/505/747</td>
<td>590/475/750</td>
<td>706/461/760</td>
<td>724/442/807</td>
</tr>
<tr>
<td>Naturally arm swing</td>
<td>687/537/734</td>
<td>634/492/732</td>
<td>712/473/726</td>
<td>719/475/765</td>
</tr>
<tr>
<td>Backward arm swing</td>
<td>701/639/662</td>
<td>624/509/710</td>
<td>714/508/684</td>
<td>731/522/701</td>
</tr>
<tr>
<td>Large backward arm swing</td>
<td>926/596/575</td>
<td>614/570/674</td>
<td>709/560/645</td>
<td>788/535/583</td>
</tr>
<tr>
<td>Forward arm swing</td>
<td>683/613/670</td>
<td>613/498/721</td>
<td>724/499/692</td>
<td>748/481/758</td>
</tr>
<tr>
<td>Large forward arm swing</td>
<td>867/612/596</td>
<td>610/525/712</td>
<td>738/520/658</td>
<td>716/521/716</td>
</tr>
</tbody>
</table>

When the arm swing angle is increased both back and front for all volunteers, the peak values in the second half decrease and the valley values increase.

Fig 4. Focal point of ground reaction force values
Result ~lateral pelvic tilt angle~

Volunteer A walks starting from the waist.

Volunteer D walks with feet as starting points.

Fig 5. The angle of lateral pelvic tilt for each gait condition for volunteer A during one gait cycle. At an angle of 90 degrees, the ground and pelvis are parallel to the ground.
If the pelvis tilts counterclockwise when viewed from the direction of travel, the angle is toward the negative side.

Fig 6. The angle of lateral pelvic tilt for each gait condition for volunteer D during one gait cycle.

Result ~mean pelvic lateral tilt angle by subject~

TABLE II. MEAN PELVIC LATERAL TILT ANGLE FOR EACH GAIT CONDITION DURING STANCE PHASE. VALUES IN BOXES ARE EARLY VALLEY/PEAK/LATE VALLEY.

<table>
<thead>
<tr>
<th>Gait conditions</th>
<th>Volunteer A</th>
<th>Volunteer B</th>
<th>Volunteer C</th>
<th>Volunteer D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without arm swing</td>
<td>88.8/91.1/86.5</td>
<td>87.8/89.1/82.5</td>
<td>86.6/88.5/84.9</td>
<td>84.7/88.6/85.0</td>
</tr>
<tr>
<td>Naturally arm swing</td>
<td>90.2/92.7/87.4</td>
<td>87.1/88.2/82.1</td>
<td>87.0/89.2/84.8</td>
<td>85.1/88.2/84.9</td>
</tr>
<tr>
<td>Backward arm swing</td>
<td>86.0/87.1/85.2</td>
<td>86.3/87.5/81.6</td>
<td>86.0/87.6/83.8</td>
<td>85.1/86.4/84.3</td>
</tr>
<tr>
<td>Large backward arm swing</td>
<td>72.7/80.1/80.1</td>
<td>87.2/88.6/80.7</td>
<td>86.3/87.6/82.3</td>
<td>85.2/85.9/83.4</td>
</tr>
<tr>
<td>Forward arm swing</td>
<td>87.8/90.1/86.8</td>
<td>86.7/88.1/82.5</td>
<td>87.1/89.0/84.7</td>
<td>84.9/87.5/84.8</td>
</tr>
<tr>
<td>Large forward arm swing</td>
<td>81.7/84.6/83.9</td>
<td>86.7/88.2/82.3</td>
<td>86.1/87.6/83.0</td>
<td>85.7/88.0/85.6</td>
</tr>
</tbody>
</table>

The common result for all volunteers was a tendency for the late valleys to decrease as the backward arm swing angle increased.

Fig 7. Focal point of pelvic lateral tilt angle
Figure 8. Lateral pelvic tilt angle and vertical ground reaction force values during the stance phase under the same conditions. The late peak of vertical ground reaction force and the timing of the decrease in the pelvic lateral tilt angle were identical for all volunteers and all conditions. These results suggest that the pelvic lateral tilt angle has an effect on the late peak of the vertical ground reaction force value.
Consideration ~variation of vertical ground reaction force values~

Regarding the relationship between vertical ground reaction force and pelvic adduction, vertical ground reaction force is correlated with acceleration of the body’s center of gravity [5].

The center of gravity of the human body in a standing still position is said to be located at the sacrum, which is part of the pelvis.

We consider that the late peak of the vertical ground reaction force value was reduced due to the upward pelvic acceleration on the kicking side.

Consideration ~pelvic angle change~

Increased in backward arm swing angle.

The opposite shoulder tilts downward.

The pelvis tilts upward as a reaction to shoulder tilt.

Changes in the pelvic lateral tilt angle occur.
Conclusion

The purpose of this paper is to experimentally clarify how the bimodality of the vertical ground reaction force changes with arm swing and to mechanically clarify what type of coupling causes this change.

In the experiment, six conditions of arm swings were set up and the mechanical parameters of each segment and vertical ground reaction force were measured for each gait condition.

Experimental analysis showed that the lateral tilt angle of the pelvis changed as the arm rotation angle increased, and the bimodal disappearance of the vertical ground reaction force was observed.

The same trend was also observed in the timing of changes in vertical ground reaction force values and lateral pelvic tilt.

The results of the present paper suggest that the lateral pelvic tilt motion induced by arm swing is involved in the bimodality of vertical ground reaction force.
Future work

To further clarify the relationship between the upper and lower extremities, we are considering an approach based on the angulation and strength of the lower extremity.

Focus on acceleration of the pelvis, lower extremities, etc.

Once the relationship between the upper and lower limbs is clarified, we intend to utilize this information in the development of a gait improvement application.
THANK YOU

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