Reaction times of normal subjects and amputees with below-knee and above-knee prostheses during stepping

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Abstract
Reaction times (RTs) of nine normal subjects and 11 amputees with prosthetic limbs were examined in standing posture and during stepping movement. There were significant differences of RTs between standing and stepping, and between the phases of the stepping cycle in both the normal subjects and the BK or AK amputees with prosthetic limbs. The attentional demand during stepping movement and the applicability of probe RT procedure to assess prosthetic limb were briefly discussed.

Introduction
Recently there have been a number of attempts to measure attentional demand of movement using the probe reaction time (RT) procedure, in which the assumption is that the lengthening of RT reflects the attentional demand of the movement (Ells 1973, Kerr 1975, Glencross and Gould 1979, McLeod 1980). Glencross (1980) suggested that this procedure would be used to investigate some issues of motor control, for instance, at various stages of skill acquisition, in the comparison of skilled and unskilled operators, and in the direct comparison of tasks. In this study we applied the probe RT procedure for the analysis of attentional demand in the control of prosthetic limbs, using stepping movement as a task.

Methods
The experiments were performed on nine normal adults, five below-knee (BK) amputees, five above-knee (AK) amputees and one with hip disarticulation. Figure 1 shows the experimental schema. The subject was asked to say "pa" as fast as possible responding to a sound stimulus while standing or during stepping movement. The swing and support phases of stepping were defined by means of foot switches, which triggered a delay circuit that operated a sound stimulator, allowing the stimulus to be applied at any point in the step cycle. There was a 50 millisecond delay from the start of each single stance phase to the onset of the stimulus, and 10 milliseconds from the start of the double support phase. The sound stimulus was randomly delivered to the subject through headphones at intervals between 5 and 15 seconds. A unidirectional microphone attached to the headphones, by which the subject's vocal response was recorded, was placed about 5 cm from the subject's mouth. The response was

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displayed on a memoscope which was triggered by an electrical pulse synchronized with the sound stimulus. Latency from the onset of each stimulus to the vocal response, RT, was measured on the memoscope which had a scale calibrated in milliseconds. Before the experimental run several practice trials were administered to make the subject familiar with the procedure. The subject performed five trials in the standing posture and then 15 trials during stepping, where every five trials were randomly assigned to the left single support phase, the right, and the double support phase. Fifteen trials for standing and for each phase of stepping were used for statistical analysis.

Results
Table 1 shows means and standard deviations of RTs in each group. There was significant difference of RTs between standing and overall stepping (normal group, t=6.46, df=8, p<0.01; BK group, t=4.73, df=4, p<0.01; AK group, t=3.07, df=4, p<0.01).

In the normal group all subjects had shorter RTs on either side during the single support phase than during the double support phase. Reaction times for the double support phase were significantly longer than RTs for the single support (left side, t=4.60, df=8, p<0.01; right side, t=5.37, df=8, p<0.01). Although there were slight differences of RTs between the left and the right single support phases, RT differences between both the support phases was not significant (t=0.03, df=8).

In the BK group RT difference between the

<table>
<thead>
<tr>
<th>Stepping</th>
<th>n</th>
<th>Standing</th>
<th>Overall</th>
<th>Double support</th>
<th>Left support</th>
<th>Right support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal subjects</td>
<td>9</td>
<td>208.5 (30.0)</td>
<td>237.4 (29.2)</td>
<td>243.3 (28.5)</td>
<td>234.5 (28.3)</td>
<td>234.5 (31.1)</td>
</tr>
<tr>
<td>B-K amputees</td>
<td>5</td>
<td>241.8 (33.4)</td>
<td>271.0 (32.6)</td>
<td>271.5 (35.8)</td>
<td>267.8 (30.6)</td>
<td>273.6 (33.2)</td>
</tr>
<tr>
<td>A-K amputees</td>
<td>5</td>
<td>247.0 (67.8)</td>
<td>273.3 (73.4)</td>
<td>284.6 (75.5)</td>
<td>268.8 (76.1)</td>
<td>266.4 (70.5)</td>
</tr>
<tr>
<td>Hip disarticulation</td>
<td>1</td>
<td>259.1</td>
<td>292.9</td>
<td>310.9</td>
<td>290.8</td>
<td>276.9</td>
</tr>
</tbody>
</table>

Fig. 2. Reaction time differences (milliseconds) between double and single support phase (see text). White bar—normal side; black bar—prosthetic side; shaded zone—normal range.

Discussion
The present results indicated that RTs were longer during the stepping movement than in the standing posture, and that RTs depended upon
the phase of stepping cycle. Generally, the less difficult and the more automatic the movement is, the less disturbance it should exert on the probe RT. Although the stepping movement is well automatized, it still demands some attention compared to standing.

An unexpected result was longer RTs of normal subjects in the double support phase of stepping movement. Since the upright posture with double limb support is biomechanically more stable than that with the single limb support, the former would demand less attention. However, the result did not support this assumption. The control of stepping movement can be understood in terms of central programmes and reflex interaction. The stepping of one limb is composed of the swing and the support phase alternately. Since the double support phase corresponds with the phase shifting stage, the control programmes of ongoing movements for each limb should be changed at this phase and thus the process would demand more attention. On the other hand, the dynamic equilibrium of posture during stepping movement, either with double or single support, is kept through the reflex mechanisms in which the attentional demand could be minimal.

Although a marked lengthening of RTs during the single support phase in some subjects with prosthetic limbs was observed, the biomechanical correlation was not examined as the number of subjects in this study were limited, thus no firm conclusions could be reached without considering kinematic and/or kinetic features and also more cases.

However, this observation would imply that these subjects lacked the stability of single limb support with the prosthesis and/or made an effort to control the swing phase of the prosthetic limb.

Since the reduction of RT during performance points to the decrease of attentional demand of task, this method may be applicable and useful to detect problems of the prosthetic limb and to assess the prosthetic fitting.

REFERENCES


