Implicit and Explicit Real-time Feedback for Reducing the Knee Adduction Moment during Gait Retraining

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INTRODUCTION
Gait retraining shows promise as an intervention for medial compartment tibiofemoral osteoarthritis. Walking speed, medio-lateral trunk sway, medial thrust, and hip internal rotation and adduction can influence the external knee adduction moment (KAM) [1-4], a measure correlated with the onset, progression, and severity of the disease. Gait alterations have been shown to reduce the KAM on average for a given population, however large between-subject variability means that the intervention will be ineffective for some individuals. Real-time feedback can improve gait retraining by providing knowledge of performance during training. We examined (two types of real-time feedback, 1) implicit feedback: subjects were given knowledge of the overall performance and made self-selected kinematic changes to achieve the goal, and 2) explicit feedback: subjects were explicitly trained to alter specific kinematic movements. We hypothesized that both forms of real-time feedback would elicit significant changes to the KAM. Furthermore, since implicit feedback leaves the type and amount of gait alteration open to the subject while explicit feedback trains exact movements, we expected explicit feedback to have less subject-to-subject variation in KAM reductions compared with implicit feedback.

METHODS
Data collection was performed with a marker based motion capture system (Vicon plc.) and a split belt force-plate treadmill (Bertec Corp.). Data were processed in real-time by streaming marker and force values from Vicon Nexus to Matlab (Mathworks Inc.) via TCP/IP.

Two studies were performed to test implicit and explicit real-time feedback for gait retraining. Altogether, 25 healthy subjects participated after giving informed consent in accordance with Stanford University’s Institutional Review Board. During the implicit feedback study eight participants received visual feedback about their KAM (measured as the first peak during stance) on a computer monitor, and eight received tactile feedback of KAM through a vibration motor strapped to the left forearm (Figure 1A). Initially, a trial was performed without feedback to record the baseline KAM value, which was the first peak of the knee adduction moment averaged over the last 10 steps. During the experimental trial feedback was given on each step, and subjects were instructed to converge to a symmetric and sustainable gait by iterating various gait modifications in an attempt to lower their KAM. Participants were verbally instructed on possible effective gait modifications and then given freedom to self-select an altered gait.

For the explicit feedback study, nine subjects were given tactile feedback through vibration motors and a skin stretch device [5,6] to modify three gait parameters: foot progression angle, tibia angle, and medio-lateral trunk sway angle (Figure 1B). The target KAM reduction was 30% or greater. A trial was performed initially to measure baseline KAM values. In subsequent trials subjects were trained to make changes to each gait parameter individually, and the corresponding response in KAM was recorded. For the experimental trial, subjects were explicitly trained to adopt a combination of gait parameter modifications based on a linear model between individual gait parameters and KAM. Student’s t-tests were performed to compare baseline and final gaits.

RESULTS
All subjects significantly reduced their KAM through real-time feedback training (p ≤ 0.003, Table 1). Results for implicit feedback were nearly identical between visual and tactile feedback. Explicit feedback showed larger reductions in KAM and less variation (6.2% compared to 16.0% standard deviation) compared with implicit feedback.

<table>
<thead>
<tr>
<th>Feedback</th>
<th>Knee Adduction Moment (%Ht*BW)</th>
<th>Percent Change</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Final</td>
<td>Average</td>
</tr>
<tr>
<td>Implicit Vision</td>
<td>4.07</td>
<td>3.29</td>
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<tr>
<td>Implicit Tactile</td>
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<td>3.09</td>
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<tr>
<td>Explicit Tactile</td>
<td>4.14</td>
<td>2.59</td>
<td>36.1%</td>
</tr>
</tbody>
</table>

Table 1: Experimental results (SD=standard deviation)

DISCUSSION
The results of this study support the hypothesis that both implicit and explicit real-time feedback can be used to significantly reduce the KAM. Further, it was shown that explicit feedback had less subject-to-subject variation suggesting that it may be more appropriate if a minimum target KAM reduction is required for each individual. The variation difference is likely due to the fact that explicit feedback removed the freedom for subjects to choose their own gait modifications. Though vision and tactile feedback showed similar results, there are important qualitative differences. Visual feedback may be the simplest to implement, while tactile feedback utilizes skin sensory signals leaving vision available for other tasks. Additionally, tactile feedback is portable (worn on the body), which is particularly important for implementing a gait retraining system outside the clinic. With such a system patients could walk around the home or outside on the sidewalk receiving tactile feedback that is not distracting to their vision. The feedback modalities introduced and tested in this study show potential as viable interventions for reducing the onset and progression of medial tibiofemoral osteoarthritis by effectively altering knee joint loads.

REFERENCES