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# Implicit Visual Distortion Modulates Human Gait

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*Abstract*—**We are investigating different adaptive strategies for training with the MIT-Skywalker, a novel robotic device for gait training. In this paper, we describe our studies on an implicit "visual distortion" paradigm and demonstrate its potential on a set of experiments with healthy subjects. Our results suggest that a gradual distortion of visual feedback of step symmetry, during a treadmill walking exercise, induced changes away from symmetry. This implies a contribution of supraspinal brain circuitry for the control of gait and that a therapeutic program which includes a visual feedback distortion without any explicit knowledge of the manipulation may provide an effective way to help patients correct gait patterns; it is one of the potential manipulations of our adaptive algorithm during gait training.**

## I. INTRODUCTION

STROKE is the first cause of permanent adult disability in the United States leading to impairments in gait [1]. Gait rehabilitation therapy has been shown to improve gait deficits and the improvements are hypothesized to result from therapy's focus on intensive, gait, strength, and balance training [2]. For the upper extremity, intensive interactive training can enhance activity-dependent plasticity in the supraspinal central nervous system, which can improve the ability to control the limb; robotic-mediated rehabilitation training has proven its merit as an adjunct to usual care [3]-[5]. For the lower extremity, results employing robotic devices have been far less promising. As an example, the larger studies employing the Lokomat (Hocoma, Zurich, Switzerland) showed inferior results that were statistically significant when compared to those produced by usual care [6], [7]. In fact, the 2010 American Heart Association guidelines for stroke care and the Veterans Administration/Department of Defense guidelines for stroke care endorsed the use of rehabilitation robots for the upper extremity but not for the lower extremity. Furthermore, an NIH sponsored large randomized clinical trial on treadmill training post-stroke did not lead to superior results when compared to a home exercise program (LEAPS Study). Thus, at least for stroke, a gait rehabilitation program that encompasses exclusively concepts of spinal cord central pattern generators delivered by either therapists (treadmill training such as LEAPS) or robotic devices (such as the Lokomat) does not appear to be advantageous. Hence we need to investigate both the process of gait neurorecovery as well as better technology that can effectively assist gait rehabilitation. We are developing new technology for gait training, including the MIT-Skywalker and the anklebot [8], [9], and investigating adaptive algorithms to track and challenge patients [10]. This paper depicts our efforts to integrate and manipulate visual feedback information. Visual feedback can be used to transform repetitive training into an interactive game and also to reinforce learning by providing a measure of patients' training performance ("knowledge of results" and "knowledge of performance"). In addition, using visual feedback, especially in the context of gait rehabilitation, may have the potential to influence correction of patients' gait movement patterns, perhaps because human locomotion appears to be associated with visual perception of movements and walking environments [11]. Therefore, the deliberate control of visual feedback received by subjects might be used to augment training, which may then enhance therapeutic outcomes [12]. At this point, we investigate the role of implicit visual distortion, in which subjects are unaware of the visual distortion as a variable of the adaptive controller for gait therapy. In our proposed method of visual feedback distortion, the right and left step lengths during a treadmill walking were measured by sensors and displayed to subjects. Then, the visual feedback of the step lengths was distorted. Subjects did not detect the visual distortions during trials. Our aim was to see how such visual feedback distortion, when implicitly provided to healthy subjects, could affect their stepping pattern, perhaps influencing gait symmetry. If we observed a certain effect of the implicit visual distortion on modulation of gait symmetry, then one might speculate that the role of supraspinal control during gait is non-negligible. We present results from a number of experiments to demonstrate that the paradigm of visual feedback distortion could potentially be used for gait rehabilitation. This approach might suggest novel rehabilitation interventions that may supplement and improve failed robot-mediated therapy approaches, perhaps even supplementing usual care.

## II. METHODS

### A. Subjects

Seven healthy young volunteers (4 male and 3 females; mean age, 27.1±2.6 yr) participated in this study. All subjects gave informed written consent before participating. The protocols were approved by the Massachusetts Institute of Technology COUHES (Committee On the Use of Human as Experimental Subjects). All subjects were familiar with

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walking on a treadmill.

### B. *Experimental protocol*

Subjects were first habituated to walk on a treadmill and they determined a comfortable walking speed (range 1.8~2.2 mile/hour) after 10 to 15 minutes of habituation. Subjects continued to walk comfortably on a treadmill while receiving on-line visual feedback of their step lengths and being instructed to "walk comfortably while looking at the visual display." The on-line visual feedback was step length information represented by bar graphs provided via a computer screen in front of a treadmill (Fig. 1). A computer screen (17" LCD monitor with 1280 by 1024 pixel resolution) was placed in front of a treadmill to display visual feedback information (the distance between subjects and the screen was about 4 feet).

The step length was defined as the distance between two feet when heel-strike occurred for one leg. The visual feedback consisted of the height of bars representing the instantaneous distance between two feet, so that the bars were gradually increased during the swing phase (two feet were getting further apart). The bar maximum height occurred when heel-stride occurred on the corresponding side, and the maximally displayed bar trace stayed on until the following swing phase began. When distorting the visual feedback, we increased the range of the bar for only one side (the right side). The distortion increments used in this study was 2%. For example, 2% of distortion changed the scaling factor between the actual right step length and the displaying bar height from 100% to 102%. In this way, subjects will visually perceive that their right step length is 2% longer than the actual length, and this percentage of distortion varied during trials.

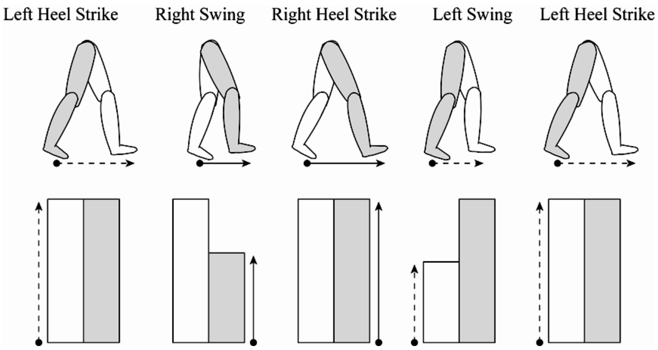

Fig.1. Example of visual feedback display used in this study. The range of the right and left step length was mapped to the visual feedback bars (bottom row). During the swing phase of a leg, the corresponding bar increases in real time proportional to the step length and stops when heel strike occurs for that leg. For distortions, we gradually changed the range of step length mapped to the visual bar.

Step length (feet movement) information was collected (at > 60 Hz) using a trakSTAR system (Ascension Technology Corporation, Burlington, VT). Two sensors were placed bilaterally over the toe, and an electro-magnetic receiver was located in front of subjects. A 17" computer screen was set up in front of a treadmill to display visual feedback information, and the visual feedback display program was written in Tcl/Tk.

The experiment was divided into two blocks. Each block began with 1 minute of steady walking at preferred speed without visual distortion followed by 6.5 minutes of visual distortion-influenced walking and ended with 1 minute of walking without visual distortion. The distortion was gradually increased by increments of 2% up to 114%, and then decreased by 2% down to 100%. Each distortion level lasted for 30 seconds. The second block followed the first one after 15 minutes of rest. The second block included a distraction task in addition to visual distortion. For the distraction task, subjects were instructed to subtract 7 out loud starting at 1000 to reduce cognitive (or volitional) resources from subjects' gait control.

### C. *Data Analysis*

Changes in step length symmetry were measured as a ratio (%) of the step length (left step length/right step length) over the entire trial. In order to test the changes in gait asymmetry induced by visual distortion with reference to initial conditions, ANOVAs with post-hoc Tukey's test was carried out in MATLAB ($p<0.05$ for significance). In addition, the linear relationship between distortion changes and gait symmetry changes was analyzed using correlation analysis and indicated by Pearson correlation coefficients.

## III. RESULTS

Figure 2 shows a single subject example of step length symmetry (expressed as a ratio) obtained from two different conditions (no distraction & with distraction task), and they are overlapped as a function of time.

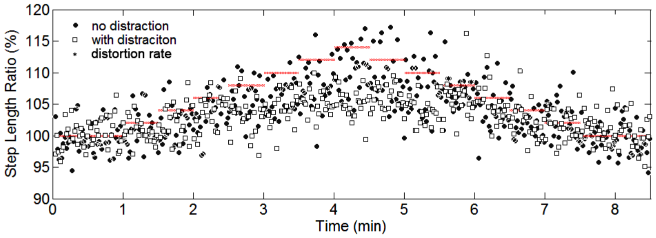

Fig.2. Example of changes in step length ratio as a function of changes in visual distortion. The horizontal axis shows time; the vertical axis shows step length ratio between the left and right actual step length. The solid circles represent the ratios during the no-distraction block, and the white squares represent those during the distraction block. The intermittent horizontal lines indicate distortion increments applied during those time periods. This plot indicates that the step symmetry was implicitly modulated in response to visual feedback distortion.

A stride consists of a right and a left step, so the number of points in the plot indicates the total number of strides during the trial. The short horizontal lines in the plot indicate the applied distortion increments at given periods. As shown in Fig. 2, for the trials with visual feedback, we observed a marked upward or downward trend in step symmetry tracking the distortion. This indicates that subjects modulated the gait symmetry to compensate the asymmetric representation of visual feedback (bar graphs). Subjects neither noticed the distortion nor realized the changes in their gait symmetry. During the second block that included the distraction task, the apparent modulation of the step symmetry was reduced supporting the role of supraspinal involvement.

In order to quantitatively estimate the changes in step symmetry, we analyzed data separately between when the distortion was increased and decreased. Figure 3(a) shows the changes in step symmetry (y-axis) as distortion was increased (x-axis) for all seven subjects. The bars represent the mean of step length ratios per each different distortion increment, and different grayscales in the bars indicate different subjects. The small square markers on top of the bars show the mean ratio for the group. For each set of individual subject data, we performed the Tukey's multi comparison test to investigate whether the induced changes in step symmetry were significant compared to the baseline ($p<0.05$ for significance). An asterisk (*) under the bar indicates that they were statistically different, and we provided the percentage of subjects who showed significant changes in step symmetry for different distortion increments. For instance, all seven subjects (100%) showed significant modulation in step symmetry when the distortion increment became 108% (Fig. 3(a)). On the other hand, Figure 3(b) shows the changes in step symmetry as distortion was decreased from 114% to 100% for all seven subjects. For convenience, when distortion was decreased, the changes in step symmetry were expressed in comparison with the mean of measured ratios during the 114% of distortion (the highest distortion rate). The results of these experiments show that subjects spontaneously modulated spatial gait symmetry in response to visual feedback.

Figures 3(c) and 3(d) show the corresponding change in step symmetry when the distraction task was added. While there was a larger variation of symmetry ratio among subjects, the distraction task appeared to reduce the step symmetry modulation.

In order to estimate the strength of the relationship between visual distortion and induced step asymmetry, we examined the correlation of both. On average for these subjects, correlation analyses revealed a moderate trend in modulating step symmetry in response to visual feedback (Fig. 4). With the distraction task, the correlation became less significant than trials with no-distraction.

We also examined the differences in the effect of visual distortion on gait symmetry changes between the no-distraction and the distraction blocks. Figure 5 shows an example of changes in step length symmetry as a function of changes in distortion increments over the entire trial, averaged across all of subjects for the two different conditions. We performed a paired t-test to examine statistical differences in step symmetry between no-distraction and distraction blocks. Significant differences were detected when the distortion rate was greater than 6% when increasing and decreasing the distortion.

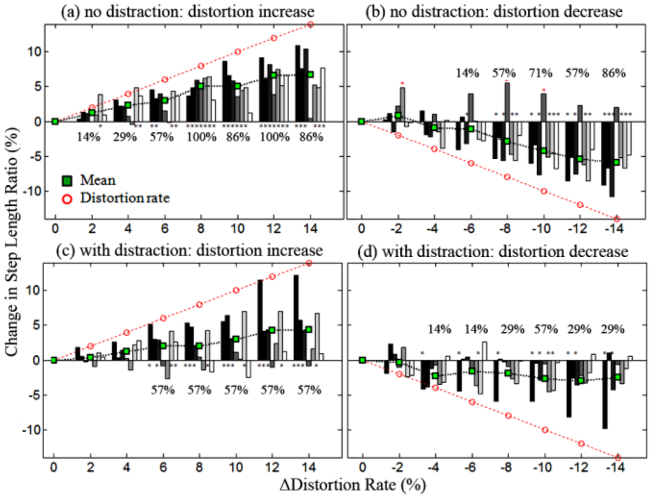

Figure 3. Changes in step length ratio as a function of changes in visual distortion for all seven subjects. The left plot shows changes in step length ratio for the first half of trial when distortion was increased, and the changes were referenced to the beginning of a trial. The right plot shows changes for the half trial when distortion was decreased, and the changes were referenced to the highest distortion rate (114%). The horizontal axis shows changes in distortion rate from the initial periods (100% and 114%), and the vertical axis shows changes in step length ratio from the mean ratio of the initial periods. The square marks represent group mean values, and the small circles indicate distortion changes applied during trials. The percentage of subjects who showed significant changes in step length ratio at given distortions among all seven subjects is also shown for each different distortion.

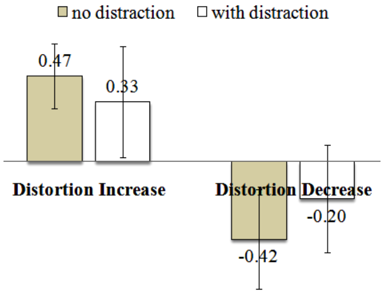

Figure 4. Mean correlation coefficient calculated between the changes in step length ratio and the changes in visual distortion when the distortion was increased (a) and decreased (b).

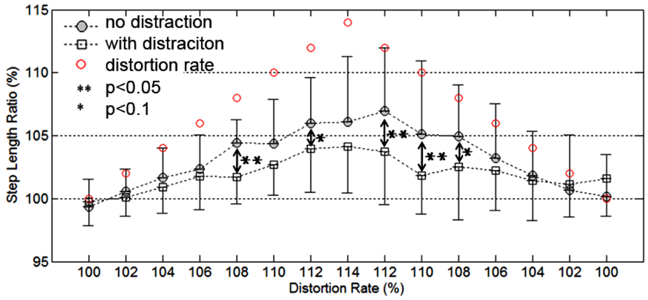

Figure 5. Changes in step length ratio as a function of changes in visual distortion ±1 standard deviation, averaged across all seven subjects for conditions of no-distraction and with-distraction. The step length ratio was calculated by 100 * the measured left step length/ the measured right step length. ***p*<0.05; * *p*<0.1; paired *t*-test

## IV. DISCUSSION

Neuronal control of human locomotion appears to require the integration of different sensory information including visual, vestibular, and somatosensory systems. One of the noteworthy effects of visual feedback is that gait patterns are, not only explicitly but also implicitly, influenced by visual perception of walking. It has been shown that changing the speed of virtual environments using virtual reality technology influences balance or modulates walking speed [13]. These results suggest the existence of links between visual perception of movements and locomotion. While numerous studies have examined the role of visual information on the control of some gait parameters, very little attention has been devoted to utilizing the effects of visual perception on gait modulation from a rehabilitation point of view. If deliberate control of visual information received by subjects can induce changes in certain gate patterns, we could potentially use it to augment gait training.

Here we showed that implicit visual feedback distortion induced changes in gait symmetry (Fig. 2 and 3). Moreover, when the distortion was varied, the observed step symmetry changes increased or decreased accordingly. As shown in Fig. 3(a), most subjects showed significant changes in step symmetry when distortion was greater than a certain range, which was 6 or 8% in our experiment. During post-experiment debriefing, all subjects remained unaware of the presence of visual feedback distortion. They also thought that they were maintaining step symmetry, remaining unaware of changes away from a symmetric gait pattern. It looks as though visual perturbation affects the other afferent signals coming from the lower limbs [14].

With distraction task, we observed the overall reduction on the effect of visual distortion (in Fig. 3(c) and 3(d)). The relationship between the changes in visual distortion and the changes in step symmetry with distraction was lower than in the no-distraction block (Fig. 4). Perhaps more surprisingly, although the amount of effect of changes was reduced, the induced change of step symmetry was still observed with the distraction task (Fig. 3(c), 3(d), and 5). These results suggest that implicit visual feedback distortion may cause non-volitional modulations in gait control.

We found this very interesting because our approach to visual feedback distortion was quite distinct from most other studies using virtual reality technology, where the whole visual scene of artificial environments was perturbed to evoke an illusion and to induce modulations of gait. The visual information we provided was simple bar graphs representing step length, and it did not evoke any illusion in visual field on the retina. However, subjects spontaneously modulated gait pattern in response to the visual feedback distortion. These results might herald a promising approach for gait rehabilitation because the paradigm of visual feedback distortion can be used as a supplemental variable of our adaptive algorithm to drive correction of affected gait patterns or to encourage patients' movements beyond their volitional efforts. Further study is in progress to develop and test the feasible benefit of visual feedback distortion paradigm for clinical trials and incorporating it in our adaptive algorithm for gait training.

## ACKNOWLEDGMENT AND DISCLOSURES

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