CLOSED-LOOP AUGMENTED REALITY FOR MOVEMENT DISORDERS

By Yoram Baram

Neurological disorders, such as Parkinson's disease (PD) and multiple sclerosis (MS), often entail mobility impairment. Traditionally, gait rehabilitation, whether by means of physiotherapy or pharmacological treatment, has focused on improvement of muscle strength and reduction of spasticity (Armutlu et al., 2001). However, the main causes of motor impairment in such cases lie in dysfunctional brain structures and neural information pathways. Visual feedback cues in the form of earth-stationary transverse lines have been found to improve the walking abilities of patients with PD (Martin, 1967; Azulay et al., 1999). Moreover, deficits in the functional neuroanatomy underlying gait in PD patients were found to be compensated by visual cues (Hanakawa et al., 1999). Specifically, the right

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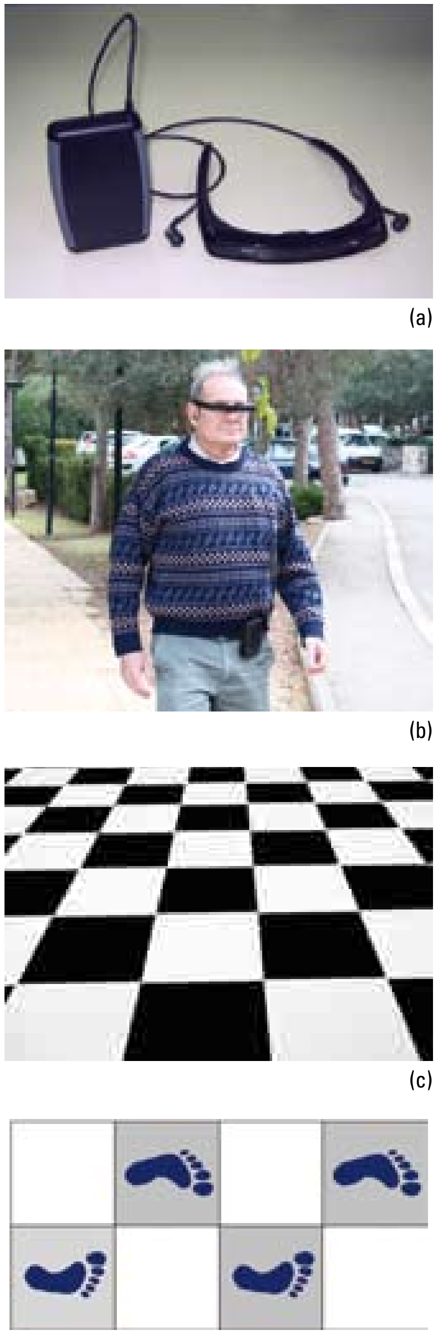
lateral pre-motor cortex, which is mainly regulated by cerebellar inputs, was activated to a greater extent in PD patients than in age-matched healthy individuals by visual transverse lines. On the other hand, healthy individuals activated mainly the supplementary motor area (SMA), which was underactivated in PD patients. It appears, then, that visually enhanced gait employs different brain pathways in PD patients compared to healthy individuals, bypassing the impaired SMA function.

Early attempts to improve gait by artificially-generated auditory and visual signals have produced open-loop systems, which, being inherently unstable, are unsafe to patients. A mathematical analysis of the stabilizing effects of earth-stationary visual feedback cues on gait (Baram, 1999) has led to the development of a wearable augmented reality apparatus, depicted in Fig. 1 (a, b), which, employing body-mounted inertial sensors, generates earth-stationary visual cues (Baram, 2004). The checkerboard tiles geometry of the visual display, depicted in Fig. 1(c), is matched to the glide-reflection symmetry of human locomotion (Livio, 2005). As illustrated by Fig. 1(d), the visual feedback regulates the motor task, producing an even (glide-symmetric) gait pattern, better balance, and safer, more efficient mobility. Even if the resulting gait pattern is not perfectly matched to the visual tile pattern, improvement in that direction translates into improvement in gait. In addition to the visual feedback cue delivered by the display, the device also produces an auditory feedback cue in the form of a clicking sound delivered through earphones in response to every step. In contrast to open-loop, metronome-like devices, which attempt to impose a walking pace on the patient by a constant auditory cue, the feedback device produces an auditory cue matched to the walking pattern. A balanced steady walk will generate a rhythmic auditory cue. Any deviation from such a gait pattern will result in a deviation from the auditory rhythm and will be corrected by a change of gait in a feedback fashion. The head-mounted display and earphones bring the sensory feedback signals closer to the sensors – the eyes and the ears, making the sensory effect more pronounced, easier to learn.



(a) (b) (c) (d)

Figure 1. (a) Augmented reality apparatus. (b) Walking with apparatus. (c) Checkerboard tile pattern displayed by apparatus. (d) Gait regulation by visual feedback.

Clinical trials have shown a significant gait improvement in patients with PD using the augmented reality apparatus (Baram et al., 2002). In particular, patients who suffered from freezing of gait were able to walk without freezing, which, in contrast, was found to be exacerbated by open-loop visual cuing. Patients with MS using the device also improved their balance and gait substantially (Baram and Miller, 2006). Auditory feedback cues were found to improve gait in a manner complementary to that of visual cues, increasing walking speed more than stride length (Baram and Miller, 2007). Moreover, gait improvement by either visual or auditory feedback was found to last beyond the training period (Baram and Miller 2006, 2007), suggesting a new treatment modality for neurological gait disorders.

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