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Asymmetrical loading during non-visual navigation

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HIGHLIGHTS

- Asymmetrical loading changes non-visual navigation along a triangle.
- Loading causes both: angular and linear deviations.
- Clockwise and counterclockwise locomotion patterns depend on the loaded shoulder.
- There is habituation effect as well as unloading effect.
- This testing has potentials to be of benefit for revealing subclinical pathology.

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ABSTRACT

Since previous studies showed that loading influences posture and gait, the aim of the present study was to determine the effect of asymmetrical loading on locomotion. The following questions were posed: is there a habituation to asymmetrical loading and what is the effect of immediate unloading? Nine healthy subjects (4 males and 5 females) were tested. They had to memorize visually a triangle drawn on the floor and then to walk clockwise and counterclockwise along it in darkness and blindfolded under the following conditions: baseline, loading of right shoulder with 20% of the body weight, after 30 min of habituation to the weight, and immediately after unloading. The turns in degrees around the angles and the distance of the path in cm were measured. The present study demonstrated that asymmetrical loading, which leads to changes in the somatosensory afferentation, affects the human locomotor pattern. There is a habituation effect as well as an unloading effect. There was also a difference between the changes in clockwise and counterclockwise locomotion. Several hypotheses are discussed to explain the results obtained under all conditions.

1. Introduction

Earlier studies have shown that loading influences posture and gait. Hong & Brueggemann [7] and Hong & Cheung [8] demonstrated that 20% of the body weight induces an increase of trunk inclination of 9–10 year-old children while standing and walking. Ledin et al. [12] established that such additional weight affects the ability to withstand balance perturbations in the elderly. In a review article, Dietz and Duysens [5] discussed the contribution of load receptor to the leg muscle activation. Compensatory leg muscle activation depends on the actual body weight; the strength of leg extensor activation during the stance phase also depends on load during gait. Experiments in paraplegic patients have shown that the beneficial effect of a locomotor training depends on the initial degree of body unloading and reloading during the course of the training effect. Wu and MacLeod [21] demonstrated that during asymmetrical loading (medial-lateral direction) the whole body center of mass (COM) location shifted toward the loaded side. The COM was closer to the center in persons with narrow stance than in those with normal or wide stance, but the COM shifts were smaller than theoretically predicted.

In an interesting investigation, Commissaris et al. [4] studied anticipatory postural adjustments (APAs) made in bimanual whole-body lifting, using a mechanical analysis of the downward movement phase preceding loaded versus unloaded lift. They concluded that the APAs in this lifting task served to generate an appropriate extending moment of the ground reaction force after box pick up, rather than the traditionally defined goal of minimizing anterior–posterior center of mass displacements.

All these investigations show that any change in somatosensory afferentation changes the brain's strategy for performing different tasks while maintaining body balance during standing and walking. The question is how adequate is the brain strategy to fully compensate for the change in somatosensory afferentation, i.e., does the brain correctly interpret the changed input?

Other approaches have been taken by gait studies. Some have focused on vestibular pathology, since the vestibular system is integrated with the somatosensory system during walking. A study of

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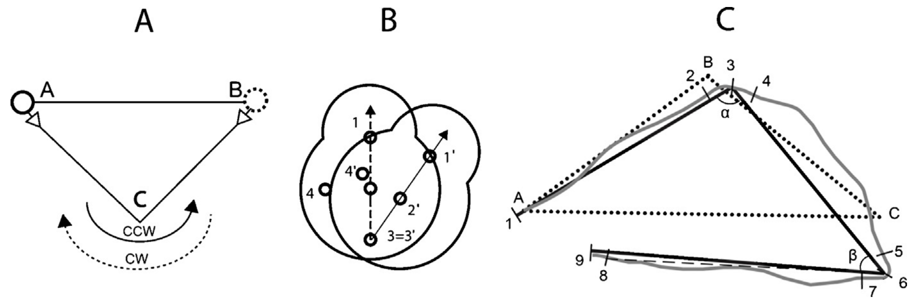

Fig. 1. (A) Trajectories and positions on the triangle. The solid line circle is the first starting configuration and the dashed line circle is the second one; the same-line pattern arrows indicate relative directions; (B) Markers of head in two different positions; (C) Triangle (doted line), real trajectory (grey curved line), and average trajectory (black solid line).

Glasauer et al. [6] showed that labyrinthine-defective patients were able to plan and execute a triangular path without vision; however, the patients failed to turn correctly around the corners. Takei et al. [18] and Ivanenko et al. [9] claim that the otoliths seem to be involved in the perception of distance, and the vestibular canals – in the estimation of angles. Other interesting studies investigated the effect of loading as well as of removing weight – unloading, on locomotion. This is of importance for life under conditions like activity during space flights, in micro- and hyper-gravity conditions. Several studies have been conducted on the influence of weightlessness on locomotion. Animal studies during the Neurolab Shuttle Mission revealed that neonatal rats that had flown in space exhibited altered locomotor behavior development which persisted for 1 month of recovery [20]. It was found that when engaged in locomotion in space humans stop using their legs, and instead use their arms and fingers to push and pull themselves [14]. Since the legs were less used for locomotion, new sensorimotor strategies emerged in microgravity. Some of this newly developed sensorimotor program "carried over" into the post-flight period, resulting in postural and gait instabilities upon return to Earth [3]. Bloomberg et al. [2] found that when attempting to walk a triangular path after flight, blindfolded crewmembers both under- and over-estimated distance walked but correctly estimated the angle turned. This finding was interpreted as indicating that the brain has difficulty reconstructing vestibular cues from the otoliths, but not from the vestibular canals. This finding could, however, be attributed to the lower walking velocity in the post-flight trial [11,15].

It is important when interpreting brain function for standing and locomotion to consider the fact that in ordinary activity the additional weight of loading is usually not symmetrically distributed on the body. That is, the loading not only causes change of the body center of mass but also asymmetrical somatosensory afferentation. Consequently the brain's strategy for performing the task correctly may not be adequate and require change. This is what presumably happens in the course of habituation. However, when, after some period, an unloading is required, the brain has to re-adapt to the initial condition, i.e., to rearrange the pattern of the reflexive reaction to return to the initial strategy.

The following questions were asked: (1) Does the performance of a locomotor task change when asymmetrical loading is applied, i.e., can the brain fully compensate for the changed somatosensory afferentation? (2) If there is change, does a process of habituation develop after a defined period of time? (3) What is the effect of unloading?

2. Methods

2.1. Participants

Nine healthy subjects (4 males and 5 females, age 27 ± 4 years, mass 63.3 ± 3.8 kg, height 171 ± 8 cm) took part in the study. All subjects were right-handed; none had musculo-skeletal, neurological or other health impairments that could affect posture or walking. The protocol was explained to the subjects before the experiment, and they gave their informed consent.

2.2. Protocol

A right angled triangle was drawn with black adhesive tape on the floor at the center of a rectangular room (11 m × 6 m × 3 m). The dimensions of the triangle were calculated by an optoelectronic system: 270 cm = the hypotenuse, and 190 cm = the two other sides.

Subjects were asked to walk in a normal way, blindfolded (EC), along this triangle. At the beginning of the experiment, they were placed at point A (see Fig. 1A). They then oriented themselves toward point C (right angle). They blindfolded themselves and, after a vocal command, begin walking along the triangle in a counterclockwise direction (CCW), in order to return to the initial position and to resume as precisely as possible their initial orientation (Fig. 1A).

At the end of the trial, the participants were instructed to keep their eyes blindfolded. To preclude any learning process, subjects had to wait to be disoriented by being randomly conducted around the room toward the new starting position (point B in Fig. 1A). In this way they would not know if they had reached the target or not. When subjects were brought near point B, they could open their eyes to orient themselves toward the right angle. When they were ready, they blindfolded themselves and waited for the vocal command to walk along the triangle as under the previous condition but this time in a clockwise direction (CW, Fig. 1A). Walking along the triangle was repeated six times: three times CCW followed by CW or three times CW followed by CCW.

Each session of tests was repeated under four different conditions:

- "baseline", subjects performed six trajectories without load and blindfolded;
- "with load", subject repeated the same protocol but wore on the right shoulder a load of 20% of body weight;
- "habituation", after 30 min of free walking along a corridor without possibility to remove the weight, the subject repeated the task;
- "without load", the weight was suddenly removed and the subject had to immediately perform the task one more time.

In this way 24 trials were recorded for each subject, 12 CW and 12 CCW, i.e., 9 subjects performed 216 trials; 215 trials were used in the analysis, because one subject's trial was missing. Each subject was tested for about 1½ h.