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Effects of task constraints on obstacle avoidance strategies in patients with cerebellar disease

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ABSTRACT

The present study examined the effects of cerebellar disease on the organization and execution of obstacle avoidance tasks. To this end, we characterized how variations in the execution demands of the subsequent obstacles in multiple obstacle crossing tasks influenced the stepping performance of the initial obstacle in patients with cerebellar degeneration (CD) by manipulating the height (6 cm and 16 cm) and distance (1 m and 2 m) of the second obstacle. Nine patients with bilateral cerebellar atrophy and nine age-matched normal controls were instructed to walk along an 8 m long pathway and step over two obstacles without contacting them. The primary finding indicated that CD patients exhibited an elevated foot clearance over the initial obstacle when the height demand of the second obstacle was increased. Such abnormal step-height adjustments in CD patients are considered as an adaptive avoidance strategy to diminish the execution demands of complex obstacle tasks and to enhance safe performance. These results suggest that the cerebellum is important for the implementation of optimal stepping strategies to be used during multiple obstacle crossings in which the obstacles have different execution demands.

1. Introduction

Walking during daily living commonly involves avoiding obstacles in the travel path, such as doorsteps, stairs, and curbs. Successful performance of obstacle crossing requires proper control of the foot trajectory through identifying the properties of the obstacles and adjusting gait patterns accordingly [1]. Failure to negotiate the obstacles may result in undesirable tripping over obstacles or falls that decrease ambulatory safety and efficiency.

While normal locomotion is known to primarily involve activation of spinal neuronal circuits and the brain, a precision locomotor movement, such as walking over obstacles, is more likely to be influenced by modulation of the supraspinal structures [2]. Neurophysiological studies of animals have shown strong involvement of the corticospinal tract when the task required voluntary selection of foot placement during obstacle avoidance [3]. In humans, enhanced neuromuscular activity at higher level was observed in the planning and organization of swing movements during obstacle crossing [4]. Individuals with central lesions (e.g., stroke and Parkinson's disease) have demonstrated abnormalities in dealing with obstacles [5,6].

Although relatively little is known about the role of the cerebellum in performing obstacle avoidance tasks, the literature suggests that the cerebellum provides adaptability to locomotor patterns by incorporating lower spinal and higher signals together [7]. Studies have shown that the cerebellum is essential adjusting gait patterns during walking and that dysfunction of this neural structure severely disrupts lower limb control during obstacle crossing [8]. For example, individuals with cerebellar damage demonstrated decomposition of movement and hypermetria (increased foot elevation) associated with excessive knee flexion during voluntary stepping in place over a small obstacle [9].

Although previous studies have provided converging evidence of the reduced capacity of cerebellar patients to perform obstacle crossing, there is limited knowledge about how cerebellar dysfunction affects locomotor strategy in negotiating obstacles in more complex contexts. It has been reported that the properties of obstacles, such as height and width, influence step characteristics during avoidance locomotion [10]. In addition, we often encounter more than one obstacle in our daily environment, and research has shown that the presence and location of a successive obstacle altered avoidance behaviors [11]. For better understanding of avoidance strategies employed by cerebellar patients, it is necessary to examine locomotor behavior of subjects during

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multiple obstacle crossings with different execution demands. To this aim, we investigated how variations in the demands of the objects in multiple obstacle crossing tasks influence planning and execution of locomotor strategies in cerebellar patients. We hypothesized that cerebellar patients would exhibit an elevated foot clearance and decomposing step movements when the adjacent obstacles require execution of high step movements or are closer together, in performing multiple obstacle crossing tasks.

2. Methods

2.1. Subjects

Nine patients with bilateral cerebellar atrophy (four females and five males; mean age of 53.9 ± 11.9 years; mean duration of disease of 4.7 ± 3.4 years; mean height of 167.1 ± 7.4 cm) participated in the experiment (Table 1). Their atrophies were predominantly of inherited or unknown origin, except for one patient with olivopontocerebellar atrophy. Nine healthy control subjects (four females and five males; mean age of 51.4 ± 9.5 years; mean height of 169.3 ± 5.8 cm) with no neurological or general medical limitations also participated in the experiment. Patients and controls were matched for age, sex and height. In the cerebellar patient group, the diagnosis of cerebellar ataxia was confirmed by a neurologist using clinical examination and MRI scans. The subjects had a mean ICARS (International Cooperative Ataxia Rating Scale) score of 31.1 ± 7.9 out of a maximum possible score of 100 [12]. We excluded cerebellar patients who showed any extrapyramidal symptoms (e.g., weakness, rest tremor) from the study. Each subject underwent the Mini Mental State Examination to evaluate cognitive status and scored normally (≥25). The protocol was approved by the Institutional Review Board of the Korea University Medical Center, and informed consent was obtained from each subject before participation in the experiment.

Table 1
Clinical characteristics of cerebellar patients.

Patient	Age (years)	Sex	Pathology	Disease duration (years)	ICARS
CD-1	47	M	ATUN	5	23
CD-2	56	M	OPCA	1	41
CD-3	34	F	SCA3	2	35
CD-4	59	M	SCA11	8	24
CD-5	38	M	SCA6	5	44
CD-6	59	F	SCA2	3	25
CD-7	66	F	SCA3	4	26
CD-8	69	M	ATUN	12	38
CD-9	57	F	ATUN	3	24

M = male; F = female; ATUN = atrophy with unknown origin; OPCA = olivopontocerebellar atrophy; SCA = spinocerebellar ataxia; ICARS = International Cooperative Ataxia Rating Scale (a higher ICARS score corresponds to more severe symptoms).

2.2. Apparatus and procedure

The participant's task was to walk along an 8 m long pathway at comfortable pace and step over two obstacles without contacting them. The obstacle apparatus used for the test was plastic tubes (10 mm in diameter, 1.5 m in length) with each end resting on height adjustable stands, which tended to fall easily when touched. The first obstacle (6 cm high) was placed in the middle of the pathway at 4 m (Fig. 1). To test how the physical properties of the second obstacle influence avoidance strategy for the first obstacle, two different heights were used for the second obstacle; the lower height was 6 cm (low height) and the higher height was 16 cm (high height). These heights were selected because it was previously shown that each obstacle height places different demands on the neuromuscular locomotor system [10]. In addition, two different inter-obstacle distances between the first and second obstacles were used; the nearer distance was 1 m (close distance) and the farther distance was 2 m (far distance). It has been reported that depending on the position of the second obstacle, young healthy people adjusted their step characteristics by having a smaller take-off distance before crossing the first obstacle for successful avoidance of multiple obstacles in the travel path [11]. After a few practice trials familiarize with the obstacle apparatus, four trials per condition were performed with 1 min rest between trials and 5 min rest between each set of conditions. Four trials in each obstacle condition were performed in blocks presented in randomized order. Participants performed the task without gait aids during the data collection and were accompanied by a physiotherapist to provide assistance if needed. During experimentation, only four of the participants contacted the obstacle, three cerebellar patients and one normal control. All of them contacted the first obstacle due to inadequate foot clearance; the fore foot of the lead limb was not lifted high enough to go over the obstacle resulting in toe contact in swing phase. In these instances, an extra trial was collected and the error trial was excluded from analysis. The mean overall failure rate for cerebellar

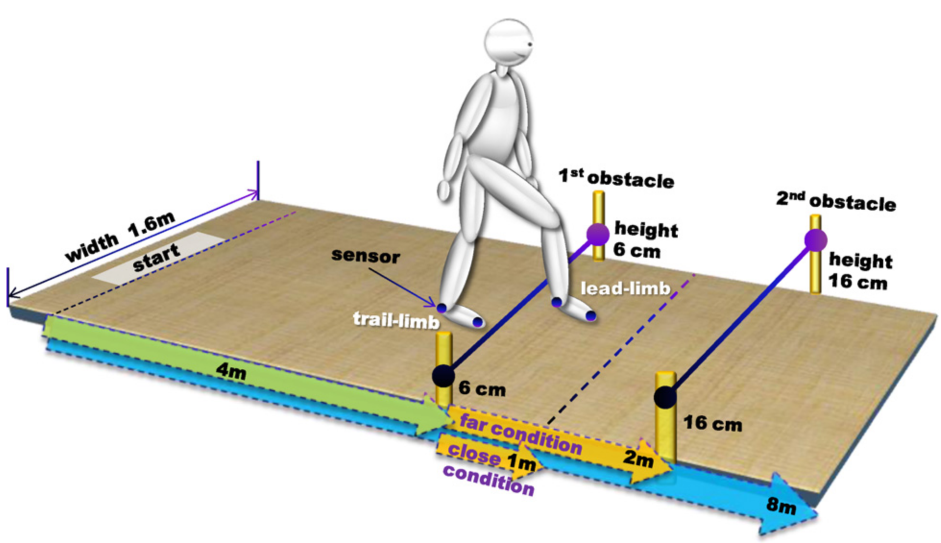

Fig. 1. Experimental set-up and test conditions. Height of the first obstacle was set at 6 cm and the second obstacle was at 6 cm (low height) and 16 cm (high height). Inter-obstacle distance was set at 1 m (close distance) and 2 m (far distance).