External cues benefit walking ability of ambulatory patients with spinal cord injury

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Background/objectives: Sensorimotor dysfunction following spinal cord injury (SCI) reduces ability of the patients to perceive information and control movements. They may need alternative sources of input to optimize their walking ability. This study investigated effects of external cues on walking ability in 33 independent ambulatory participants with SCI.

Methods: Participants' walking ability was cross-sectionally assessed under three conditions including self-determined fastest walking speed (uncued condition), and fastest walking speed with the use of external cues (visual cue and visuotemporal cue conditions). Walking ability was measured in terms of walking speed, stride length, cadence, and percent step symmetry. Findings of the three conditions were compared using the one-way analysis of variance with repeated measures.

Results: When using external cues particularly the visuotemporal cue, participants showed a significant increase in walking speed, stride length, and cadence as compared with those of the uncued condition ($P < 0.005$). The increment of walking speed was demonstrated even in participants at a chronic stage of injury (post-injury time ≥ 12 months), with severe SCI (American Spinal Injury Association Impairment Scale C), or who required a walking device.

Conclusion: The results suggested the benefit of external cues, particularly the visuotemporal cues, as a potential rehabilitation tool to improve walking speed of individuals with SCI.

Keywords: Incomplete spinal cord injury, Paraplegia, Tetraplegia, External cues, Physical therapy, Walking, Motor control, Physical rehabilitation

Introduction

Approximately 70% of patients with incomplete spinal cord injury (iSCI) regain the ability to walk.^{1,2} However, they likely walk at a slow speed with an abnormal step length, cadence, and step symmetry that negatively impact efficiency of walking and ability to participate in a community of the patients.²⁻⁴ On the contrary, walking at a sufficient speed is a crucial determinant for health status and physical function.^{2,4,5} An increase of walking speed of at least 0.3 m/s relates to the advancement of ambulatory categories.⁵ These findings suggest the importance of a treatment strategy to improve walking speed after spinal cord injury (SCI).

Several studies have reported beneficial effects of external information on motor functions in patients with brain disorders, i.e. Parkinson's disease (PD), or those with spatial or temporal neglects.⁶⁻⁹ Suteerawattananon *et al.*⁶ found that external cues, particularly an auditory cue, improved walking ability of participants with PD. The researchers suggested that supplementary information delivered with an appropriate time scale could theoretically enhance preparatory processes and improve motor patterns of the participants. However, simultaneous application of visual and auditory cues for a particular task divided attention of the participants, and hence slightly decreased their walking performance.⁶ Majsak *et al.*⁷ utilized a moving ball to provide temporal information for participants with PD to perceive visually, as the so-called

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visuotemporal cue. They found that the cue enabled participants to reach a velocity that exceeded their self-regulated maximal speed and matched the speed of healthy participants. The researchers concluded that bradykinesia reflected a deficit in internal motor drive that limited ability of the participants to efficiently modulate motor outputs and maximize their movement speed during self-regulated motor tasks. External temporal information via visual perception attributed a means of organizing timing and speed of movements that compensated for the loss of internal cueing mechanisms of the participants, and helped them to improve their reaching ability.⁷

On the contrary, patients with SCI have intact integrative capability of the brain. However, sensorimotor dysfunctions following SCI reduce their ability to organize an optimal movement pattern while walking.¹⁰ The patients may need an alternative source of input to supplement for internal deterioration and subsequently optimize their movement control. However, the incorporation of external cues in rehabilitation practice for these individuals is just at an initial stage. Amatachaya *et al.*¹¹ have reported the benefit of external cues on walking ability in participants with iSCI. However, the data arose from a total number of participants with various stages of injury, severities of SCI, and requirements of walking devices that might attribute significant influence on the outcomes. Thus, this study further explored effects of external cues in subgroups of participants with SCI with particular characteristics including subacute (post-injury time (PIT) <12 months) or chronic (PIT ≥12 months) stage of SCI,¹² American Spinal Injury Association Impairment Scales (AIS) C or D, and walking with or without a walking device. Findings of the study may provide clearer insight into the application of external cues in rehabilitation procedures for these individuals. The researchers hypothesized that external cues would enable the participants to improve their walking ability even though they were at a chronic stage of injury, had severe SCI, or walked with a walking device.

Methods

Participants

Participants were independent ambulatory patients with SCI who were consecutively admitted to a rehabilitation ward at a major tertiary referral hospital, Thailand. The criteria for participation have been previously published.¹¹ Briefly, the eligible participants had SCI from traumatic causes or non-progressive diseases, and ability to walk independently at least 17 m (50 feet) with or without a walking device (Functional

Independent Locomotor (FIM_L) scores 5–7).¹³ The exclusion criteria were any medical conditions that might affect ambulatory ability such as pain or inflammation in the muscles or joints of the lower extremities with a level of pain of more than 5 out of 10 on a visual analog scale,¹⁴ leg-length discrepancy, and spinal deformity (i.e. marked kyphosis or scoliosis). The experimental protocol was approved by the institutions' human research ethics committees. An informed consent was obtained from every participant prior to taking part in the study.

Experimental protocol

The study cross-sectionally assessed the effects of using external cues while participants walking. Each participant was involved in the study for 2 consecutive days. On the first day, participants were interviewed for baseline demographics, and underwent screening tests to ensure SCI characteristics (including causes, level and severity of injury, and PIT), baseline walking ability (FIM_L scores) and other medical conditions that might affect ambulatory ability (as indicated above). On the second day, participants were assessed for their walking ability along a 10-m walkway with or without a walking device under three conditions including self-determined fastest walking speed (uncued condition), fastest walking speed with the use of visual cue, and fastest walking speed with the use of visuotemporal cue conditions (Fig. 1). Details of each condition are as follows:

- *The uncued condition:* Participants were instructed to walk along a straight line for 10 m at their self-determined fastest walking speed without using external cues.
- *The visual cue condition (Fig. 1A):* Participants walked along a straight line at their fastest speed and stepped each pace in accordance with colored tapes that were attached on the floor at an interval equal to 40% of the participant's height.^{6,8,11}
- *The visuotemporal cue condition:* The test required a 'ball-moving machine' (Fig. 1B and C) and a tennis ball to provide a visuotemporal cue. Participants were instructed to start walking along a straight line when a tennis ball appeared from behind the barrier as fast and safely as they could to grasp the ball at the intercepting zone (a 10-cm area in the middle of the moving track, Fig. 1B and C).

The conditions were randomly ordered to minimize carryover effects that might occur due to sequences of the tests such as fatigue or learning effects. Participants performed five trials/condition with periods of rest as needed between the trials. The first

Figure 1 Conditions of tests. (A) Visual cue condition. (B) and (C) Visuotemporal condition.

two trials served as practice sessions for participants to become familiar with the tested conditions and to identify an appropriate ball speed for the visuotemporal cue condition. After sufficient rest, participants continued the other three trials which were used for data analyses of that condition. During the tests, participants had to fasten a lightweight safety belt with a physiotherapist walking alongside for safety reasons.

Outcome measures

The study measured variables relating to walking abilities including walking speed, stride length, cadence and step symmetry in which walking speed was served as a primary outcome, while stride length, cadence and percent step symmetry were used as secondary

outcomes. Prior to the test, the video recording system was calibrated using a 60-cm ruler. Then the walking ability of participants along the middle 3 m of the walkway for each condition was recorded to minimize acceleration and deceleration effects on the outcomes. The spatiotemporal data of three gait cycles were analyzed using the method of manual digitization, which was described by Said *et al.*^{15,16} and was convenient to use in a rehabilitation ward. The method had high validity compared with the PEAK motion analysis ($ICC_{3,1} = 0.95-0.99$) and high reliability ($r = 0.96$, $ICC_{3,1} = 0.94$).^{15,16} The spatial data were obtained by counting the horizontal pixels between two points and scaling with respect to the calibration object. A step length was then calculated using the average distance

Table 1 Demographic data of participants

Variables			Findings (n = 33)
Age* (years)			45.53 ± 14.85 (18–63)
Post-injury time* (months)	Sub-acute (<12 months)		4.40 ± 2.28 (2–8)
	Chronic (≥12 months)		60.63 ± 63.12 (14–108)
Gender (n)	Female		9
	Male		24
Walking devices (n)		Total	23
	Presence (FIM _L = 6)	Standard walker	18
		Crutches	4
		Cane	1
	Absence (FIM _L = 7)		10

*The data are presented using mean ± SD (range).
FIM_L, Functional independence measures locomotor score; FIM_L 6, ability of independent walking at least 50 m (150 ft) with the use of a walking device; FIM_L 7, ability of independent walking at least 50 m (150 ft) without the use of a walking device.

from the heel of one foot to the heel of the other foot. The total distance of the right and left step lengths represented the stride length. Percentages of step symmetry were computed using the formula $\left[\frac{\text{average step length of more affected side}}{\text{average step length of less affected side}} \times 100 \right]$. The temporal data were taken from that shown in the video. In order to avoid bias of the researcher while working on manual digitization (blind conditions of tests to the assessor), the visual cues (color tapes) were left on the floor in every condition. However, the tapes might confuse the participants while testing in the other conditions, thus they were instructed to look forward throughout the tests.

Statistical analyses

Descriptive statistics were applied to explain baseline demographics and findings of the study. The one-way analysis of variance (ANOVA) with repeated measures was utilized to compare the findings among the conditions. Then the *post hoc* (Scheffe) test was used to determine the differences of every pairwise condition. The level of significant differences was set at $P < 0.01$.

Results

Thirty-three participants with iSCI completed the study. All of them were able to walk at least 50 m (FIM_L scores = 6–7). Twenty-three of them walked with a walking device (FIM_L scores = 6) and 10 participants walked without any walking devices (FIM_L scores = 7, Table 1). Fourteen participants were at a sub-acute stage and the rest were at a chronic stage of injury. Twenty-seven participants had an AIS D and six participants had an AIS C. Every participant with AIS C had a chronic stage of injury (PIT = 32.25 ± 10.41 months). Other characteristics of participants are given in Tables 1 and 2.

Table 3 shows findings of the study according to the test conditions. The findings demonstrated that the visual cues assisted participants to walk with the longest stride length, but with the lowest cadence. The visuotemporal cue facilitated participants to walk with the fastest speed, highest cadence and most step symmetry. Walking speed, stride length, and cadence of participants while walking with external cues were significantly different from those of the uncued condition ($P < 0.005$, Table 3).

Fig. 2 presents results on the major variable (walking speed) based on stages of injury (subacute or chronic), severities of SCI (AIS C or D), and requirements of walking devices (walking with or without a walking device). The findings demonstrated that using the

visuotemporal cue significantly improved walking speed for most subgroup analyses ($P < 0.01$), except those with AIS C (Fig. 2). The differences in walking speed between the uncued and visuotemporal cue conditions of all subgroups ranged from 0.15 to 0.29 m/s.

Discussion

This study investigated effects of the incorporation of external information while walking in independent ambulatory participants with SCI who walked with and without a walking device. The findings showed that using external cues helped participants to improve variables relating to walking ability (Table 3 and Fig. 2). As every condition was tested at a fastest speed, the results implied that participants retained some capability that they were unable to generate by their own determination. External cues, particularly the visuotemporal cue, effectively assisted participants to modify and increase their walking speed as compared with the uncued condition even they were at a chronic stage of injury, had severe SCI, or walked with a walking device (Fig. 2). The increment of walking speed also accompanied with the improvement of other variables related to walking ability (Table 3).

In contrast to data previously published,^{6–8} participants in this study had intact integrative capability of the brain. However, disorders to the spinal cord affect sensorimotor function, and thus put higher individual constraints onto the participants, particularly those with chronic and severe SCI (AIS C). During the chronic stage of injury, the movement systems become less plastic and more limited.^{12,17} Severe SCI (AIS C) implied that the participants were faced with considerable sensorimotor dysfunction (Table 2), which obviously reduced their ability to voluntarily organize an optimal movement.¹⁸ The supplementary information assisted participants to successfully reorganize their movements and generate a better walking ability than that of the uncued condition (Table 3 and Fig. 2). However, severe impairments might limit their ability to alter movements according to the information provided by the cues. Thus, the increment of walking speed was not significant difference (Fig. 2). Nevertheless, there were only six participants with AIS C and all of them were at a chronic stage of injury. Thus, a greater number of participants are needed to support the findings.

Many participants also walked with a walking device ($n = 23$, Table 1). In general, walking devices help to increase body base of support and allow contribution of the upper extremities, thus increased levels of confidence of individuals while movements.^{19,20} However,

Table 2 Sensorimotor scores of the participants

Variables		Stage of injury		AIS classes		Level of injury	
		Sub-acute (n = 14)	Chronic (n = 19)	C (n = 6)	D (n = 27)	Tetraplegia (n = 16)	Paraplegia (n = 17)
Motor scores (scores)	UEs (50 scores)	41.58 ± 10.45	45.88 ± 7.19	45.5 ± 9.00	43.88 ± 8.91	35.75 ± 8.15	50.00
	LEs (50 scores)	43.25 ± 3.44	38.71 ± 10.40	29.25 ± 14.17	42.40 ± 5.79	44.92 ± 4.03	37.53 ± 9.49
Tactile (scores)	UEs (32 scores)	30.08 ± 2.57	30.59 ± 3.79	28.50 ± 7.00	30.68 ± 2.43	28.08 ± 4.23	32.00
	Trunk (44 scores)	39.83 ± 5.08	39.06 ± 8.31	37.50 ± 13.00	39.68 ± 6.01	37.17 ± 9.04	40.94 ± 4.96
Proprioception (scores)	LEs (36 scores)	26.50 ± 7.20	24.18 ± 9.44	24.00 ± 12.96	25.32 ± 7.97	27.00 ± 9.11	23.82 ± 8.11
	UEs* (12 scores)	12.00	11.82 ± 0.53	11.75 ± 0.50	11.92 ± 0.40	11.75 ± 0.62	12.00
	LEs** (12 scores)	11.75 ± 0.62	10.77 ± 1.60	10.75 ± 2.50	11.24 ± 1.16	10.75 ± 1.60	11.47 ± 1.12

Note: Data are presented using mean ± SD, *assessed at the shoulder, elbow, and wrist joints; 2 = intact, 1 = impaired, 0 = loss,

**Assessed at the hip, knee, and ankle joints; 2 = intact, 1 = impaired, 0 = loss.

AIS, American Spinal Injury Association (ASIA) Impairment Scale; AIS C, incomplete. Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3; AIS D, Incomplete. Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade greater than or equal to 3; UEs, upper extremities, LEs, lower extremities.

using a walking device requires substantial attention and increases time spent for the stance phase that affects walking speed.^{19,21} Application of external cues may draw attention of the participants to spatial information on the floor (visual cue condition), or to intercept the moving ball at the contact zone (visuotemporal cue condition).^{6,7} These facilitated placing the device at a further distance that allowed a greater step length and/or to increase walking cadence. Thus, they showed significant improvement of walking speed (Fig. 2).

The increment in walking speed while using the external cues implied that participants retained some ability to alter the frequency relation between the arm and leg movements.^{22,23} These movements have positive influence on trunk and pelvic rotation that is a crucial component of normal walking.^{23,24} In addition, increased walking speed correlates with the degree of independence in the home and community.^{4,5} In this study, walking speed while using the visuotemporal cue of participants who walked with a walking device

was 0.52 m/s, and the differences of walking speed between the visuotemporal cue and uncued conditions ranged from 0.15 to 0.29 m/s (Fig. 2). Van Hedel⁵ reported that walking speed of participants who walked without a walking device was 0.7 m/s, and the increment in walking speed 0.3 m/s associated with the advancement of functional ambulatory categories of participants with SCI. Thus, findings of this study suggested benefit of external cues, particularly the visuotemporal cue, as a potential rehabilitation tool to improve walking speed of the patients. In home and community settings, the visuotemporal cue can be simply applied by asking the patients to keep their walking speed in accordance with the others or walking to the target within the time allowed.

There are some methodology considerations when interpreting findings of the study. First, results of this study was cross-sectionally assessed, a further longitudinal study that investigates effects of external cues on walking training would strengthen the findings. Second, the visual cues (color tapes) were left on the

Table 3 Effects of external cues on variables relating to walking ability of all participants

Variables	Test conditions			P value***
	Uncued condition	Visual cue condition	Visuotemporal cue condition	
Walking speed (m/s)	0.50 ± 0.27	0.53 ± 0.32	0.68 ± 0.38 ^{u, v}	<0.005
Stride length* (m)	0.81 ± 0.23	0.99 ± 0.27 ^u	0.94 ± 0.28 ^u	<0.005
Cadence (steps/min)	70.23 ± 24.71 ^v	60.12 ± 26.41	80.03 ± 30.35 ^{u, v}	<0.005
Step symmetry** (%)	80.41 ± 16.82	82.70 ± 14.74	83.19 ± 17.03	0.784

Note: Data are presented using mean ± SD. Bold-faced numbers demonstrate the best performance of the variables, superscripts indicate the condition(s) with significant differences from the test condition: u = uncued, v = visual cue conditions.

*Data were taken from the total distance of the right and left step lengths.

**Data were calculated using the formula $\left[\frac{\text{step length of more affected side}}{\text{step length of less affected side}} \times 100 \right]$.

***P value from the ANOVA with repeated measures.

Figure 2 Walking speed of the participants in each subgroup. *Significant differences from the visuotemporal cue condition ($P < 0.01$). AIS, American Spinal Injury Association (ASIA) Impairment Scales.

floor in every test condition in order to minimize bias of the researcher when analyzed the data using the method of manual digitization (blind conditions of the tests to the assessor). Although participants were instructed to look forward while walking in the other conditions, they might not be able to totally ignore the cues on the floor, particularly if they had just used them. In addition, looking at the visual cues on the floor and looking forward in the other conditions may affect posture of the participants and influence outcomes of the study. Third, the study applied video recording and manual digitization for data recording and analyses because the method has been verified for its validity and reliability,^{15,16} and it is convenient to use in a rehabilitation ward. Although the researchers instructed participants to walk along a straight line, they might veer from the walkway and affect the findings of 2D analyses. Last, the researchers realized that the data were derived from small number of participants. However, they were presented and analyzed using mean $\pm$ SD and ANOVA with repeated measures in order to facilitate data comparison with other studies.

Conclusion

This study investigated effects of using external cues in independent ambulatory participants with SCI. The results suggested benefit of incorporation of external cues, particularly the visuotemporal cue, on walking ability of the participants even though they were at a chronic stage of injury, had severe SCI, or required a walking device. The findings contributed vital insight into the modification of rehabilitation procedures for these individuals. However, an intervention study, i.e.

incorporation of external cues on walking training, is needed to support effects of external cues on walking ability of these individuals.

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