Original Article

The handkerchief guide: a simple and practical method to improve ataxic gait in cerebellar subjects

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Abstract

Objective: Ataxic gait can be remarkably improved by a simple method called the "handkerchief guide" involving the patient and caregiver holding opposite ends of a handkerchief and walking together. Our objective was to assess the effect of the handkerchief guide on gait in patients with cerebellar ataxia.

Methods: Gait analysis was carried out on seven patients with degenerative cerebellar disease (DCD), seven patients with unilateral cerebellar vascular disease (CVD), and seven healthy control (HC) subjects. All subjects performed two walking tasks: free walking (FW) and handkerchief-guided walking (HGW) on a 10 m pathway. In the HGW condition, each subject walked with the caregiver while maintaining slight tension on the handkerchief. The HCs and patients with DCD held the handkerchief with their right hand, while the patients with unilateral limb ataxia due to CVD grasped it with their affected and unaffected hands in different trials. We measured 10 gait parameters.

Results: The HGW attenuated body-sway, lengthened step, and increased gait velocity in patients with cerebellar ataxia. In DCD, the HGW significantly improved seven parameters. In CVD, HGW with the affected hand improved five parameters, and HGW with the unaffected hand improved seven parameters.

Conclusions: The HGW stabilized upright posture in patients with cerebellar ataxia during level-ground walking, probably by enabling subconscious postural adjustments to minimize changes in the arm and hand position relative to trunk, and in arm configuration. This led to improvement of gait performance. The handkerchief guide may be useful for walk training in patients with cerebellar ataxia.

Abbreviations: COM, center of mass; COG, center of gravity (projection of the COM onto the ground plane); COP, center of pressure; CVD, cerebellar vascular disease; DCD, degenerative cerebellar disease; FW, free walking; HAT, head, arms, and trunk segment; HC, healthy control; HGW, handkerchief-guided walking.

(Rinsho Shinkeigaku (Clin Neurol) 2015;55:311-319)

Key words： stroke, gait ataxia, spinocerebellar ataxia, posture, rehabilitation

Introduction

Cerebellar ataxic gait is characterized by widened stance, prolonged double support period, variable foot placement, irregular foot trajectories, and a resulting unstable, stumbling path with veering to the more severely affected side[1)–4)].

Contact of the finger with a stationary surface can greatly attenuate postural sway during standing and walking, even when the touch is so light that it does not provide mechanical support[5)–7)]. Improvements in postural stability with light touch have been reported in older adults[8)], in individuals with vestibular impairments[9)], in congenital blindness[10)], and in patients with peripheral neuropathy[11)]. It has been reported that touching a non-rigid surface such as a cloth curtain suspended from the

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(Received: 17 June 2014)

Table 1 Clinical data for patients with cerebellar disease.

Patient	Age (y)	Gender	Diagnosis	LOI	Height (cm)	Weight (kg)	Upper limb score	Lower limb score	Rating (/100)
D1	64	M	MSA-C	2 y	172	70	I	I	18
D2	70	F	MSA-C	2 y	150	61	I	I	20
D3	69	M	ILOCA	2 y	171	67	I	I	24
D4	71	M	ILOCA	2 y	175	72	I	II	28
D5	73	F	ADCD	6 y	150	50	II	I	29
D6	27	M	SAOA	3 y	176	59	III	III	37
D7	66	M	DRPLA	19 y	169	58	III	III	44
Mean ± SD	62.9 ± 16.1			5.1 ± 6.3 y	166.1 ± 11.3	62.4 ± 7.7			28.6 ± 9.3
C1	72	M	Infarction left SCA	3 mo	163	74	I	II	12
C2	66	M	Hemorrhage left SCA	0.5 mo	167	74	I	II	14
C3	67	F	Hemorrhage right SCA	2 mo	150	57	I	II	21
C4	69	M	Hemorrhage left SCA	3 mo	167	61	II	II	34
C5	62	M	Hemorrhage right SCA	3 mo	165	52	II	II	37
C6	56	M	Hemorrhage left SCA	5 mo	169	72	II	III	38
C7	56	F	Hemorrhage left SCA	5 mo	154	55	II	III	40
Mean ± SD	64.0 ± 6.2			3.1 ± 1.6 mo	162.1 ± 7.4	63.6 ± 9.4			28.0 ± 12.0

Ataxia was clinically assessed on Hirayama and Kita's ataxia scale[14] and on the International Cooperating Ataxia Rating Scale (ICARS)[15]. In the patient column, "D" indicates a patient with degenerative cerebellar disease, while "C" indicates a patient with unilateral cerebellar vascular disease. ADCD = autosomal dominant spinocerebellar degeneration; DRPLA = dentato-rubro-pallido-luysian atrophy; ILOCA = idiopathic late onset cerebellar ataxia; LOI = length of illness; MSA-C = multiple system atrophy-cerebellar dysfunction subtype; SAOA = sporadic adult-onset ataxia of unknown etiology; SCA = superior cerebellar artery.

ceiling reduced postural sway in normal subjects[12].

We have found that ataxic gait in patients with cerebellar diseases is remarkably improved by just holding a handkerchief with one hand while a caregiver holds the other end and walks along with the patient[13]. The aim of the present study was to assess by gait analysis the effect of the handkerchief guide on gait in patients with cerebellar ataxia.

Methods

Subjects

We examined 14 patients with cerebellar ataxia, comprising 7 patients with degenerative cerebellar diseases (DCD) and 7 patients with unilateral cerebellar vascular disease (CVD) (Table 1). All patients were able to walk alone or with assistance for 10 m. All patients had mild to moderate cerebellar ataxia, but did not have pyramidal sign, extrapyramidal sign, sensory disturbance, or muscle weakness. All patients with DCD showed symmetrical cerebellar ataxia, while those with CVD had unilateral cerebellar ataxia. The severity of cerebellar ataxia was evaluated using the Hirayama and Kita ataxic scale[14], which ranged from 0 (no ataxia) to V (extreme ataxia) (Table 2), and the International Cooperating Ataxia Rating Scale (ICARS)[15], which consisted of four items: 1) Posture and gait disturbance (34 points), 2) Limb ataxia (52 points), 3) Dysarthria (8 points), and 4) Oculomotor disorders (6 points). Higher point totals corresponded to more severe motor ataxia. All patients underwent head MRI and CT examinations. Genetic screening was also done, revealing that one of the patients with DCD had dentato-rubro-pallido-luysian atrophy (DRPLA).

Two healthy females and five healthy males with a mean age of 61.7 ± 3.0 (range: 59–66) y, mean height 166.9 ± 11.1 cm, and

Table 2 Scaling of cerebellar ataxia by Hirayama and Kita[14].

A. Severity of lower extremity (gait) involvement is graded as follows.
Grade I (slight degree) : walks independently.
Grade II (mild degree) : walks with occasional assistance.
Grade III (moderate degree): assistance from others is always needed to walk.
Grade IV (severe degree) : wheelchair-bound.
Grade V (extreme degree) : bedridden.
B. Severity of upper extremity involvement is graded as follows.
Grade I (slight degree) : hand is mildly unskillful.
Grade II (mild degree) : hand is unskillful, but there is no need for mechanical aids for eating. Writing a letter is possible but the letters are poor.
Grade III (moderate degree): hand is very unskillful and mechanical aids are required for eating. Writing is possible but the letters are difficult to read.
Grade IV (severe degree) : hand is extremely unskillful and assistance from others is required for eating. Writing is not possible.
Grade V (extreme degree) : not only the hand, but also the arm is unskillful and useless. Assistance from others is required continually for everyday tasks.

mean weight 60.8 ± 12.9 kg served as healthy controls (HC).

This study was approved by the local ethics committee, and all patients gave written informed consent.

Study protocol

A. Task

All subjects performed two tasks, free walking (FW) and handkerchief-guided walking (HGW), in that order. In FW, each subject was instructed to walk at a self-determined speed on a 10 m pathway. The caregiver walked along with the subjects. In HGW, a 47 cm cotton handkerchief was folded along a diagonal line, and was then folded again at the midline to form a triangular shape. The subject and the caregiver held opposite ends of the handkerchief (Fig. 1). Each subject walked together with the caregiver, while maintaining slight tension on the handkerchief by pulling it lightly towards the subject. Apart from this general guideline, the subjects received no further instruction as to the amount of pulling force to be exerted, and no attempt was made to regulate pulling forces during the experiments. The caregiver was required to check whether the subject was holding the handkerchief, not to pull the handkerchief intentionally, and to prevent patient falls. In HC subjects and patients with DCD, we analyzed the gait with the dominant right hand holding the handkerchief, while in patients with CVD, we analyzed the gait when each hand held the handkerchief to determine the influence of unilateral lesions on the ipsilateral hand (ataxic hand) and on the contralateral hand (normal hand).

Fig. 1 Handkerchief-guided walking.
A subject and a caregiver grip opposite ends of a handkerchief folded into a triangular shape. The subject walks along with the caregiver while maintaining light tension on the handkerchief by pulling lightly toward the subject. Refer to Table 1 for details on patient D7 with cerebellar disease.

B. Gait analysis

Twelve infrared-reflecting markers 20 mm in diameter were bilaterally attached to the leg and trunk at the following positions: 1) foot, head of fifth metatarsal bone; 2) ankle, lateral malleolus; 3) knee, lateral knee joint space; 4) hip, the straight line from the greater trochanter of the hip joint to the anterior superior iliac spine 1/3 from the greater trochanter; 5) shoulder,

the center of acromion; 6) vertex, a hat with one marker; and 7) one dummy marker, right posterior superior iliac spine. The subjects had the full marker set applied and were then asked to walk on a 10 m walkway in the laboratory 8 to 10 times. The positions of the markers were captured with a 6-camera Vicon 370 system (Oxford Metrics, Oxford, UK). Forces were measured with force plates instrumented with strain gauges (2.4 m long and 1.2 m wide; G-3100S, Anima, Tokyo, Japan). A 6-camera video-based kinematic data acquisition system synchronously collected the unprocessed kinematic and force plate data at 60 Hz following the method of Kunimi et al.[16]. The marker trajectories were preprocessed using commercial software provided by Vicon. This software fitted a clinically evaluated kinematic model to the marker trajectories, and extracted velocities and the path of the center of mass. It also generated animated stick figures that were used to identify the heel-strike and toe-off times during walking. Kinematic data were sampled within a stationary orthogonal laboratory coordinate system defined by a vertically oriented z-axis and a y-axis parallel to the path of progression.

Assessment of motor performance on two independent levels

A. Qualitative analysis of body sway and forward progression

Qualitative analysis of the sway of the head, arms and trunk (HAT), and of the center of mass (COM) was performed in the frontal and lateral planes of the stick figures (Fig. 2). Horizontal trajectories of the center of gravity (COG) and the center of pressure (COP: geometric mean of all pressure applied to the sole of the foot) in relation to foot placements provided other qualitative data to be analyzed (Fig. 3).

B. Quantitative assessment of gait parameters

The 10 gait parameters were measured, or calculated over 15–20 gait cycles, as follows. We quantified walking performances with 10 gait parameters specially selected to capture known features of cerebellar gait ataxia (Fig. 4). We measured (a) lateral body sway of the head and of the COM, calculating the mean amplitude (the mean unsigned deviation from the mean position in the walking cycle) of medial-lateral (ML) body sway at the head and COM; (b) temporal parameters: the duration of the stance phase and the double limb support time. These two temporal parameters are increased when balance is compromised due to gait instability[17]; (c) spatial parameters: gait velocity, step length, cadence, step width, step-length variability, and step-length ratio. Variability measures were calculated using the coefficient of variation CV. The step length ratio is useful as a measure of step symmetry, the ratio rising closer to 100% as the gait improves[17].

C. Statistical analysis

We used a non-parametric test because of the relatively small sample size in each of the cerebellar disease groups. First, we compared gait performance between the HC and cerebellar disease groups during FW using the Kruskal-Wallis test. When the test yielded a significant effect, post-hoc analysis was done using the Mann-Whitney U test. Second, we compared walking performance between FW and HGW using the Wilcoxon signed-rank test in HC and patients with DCD (*, $P < 0.05$). Finally, we compared walking performance among FW, HGW with ataxic hand, and HGW with normal hand using the Friedman test in patients with CVD. When the Friedman test yielded a significant effect, post-hoc analysis was done using the Wilcoxon signed-rank test for pairwise comparisons between assessments. For the two post-hoc analyses, we report two significance levels: uncorrected (*, $P < 0.05$) and Bonferroni-corrected for multiple comparisons (**, $P < 0.05/3$).

Results

Free walking in patients with cerebellar disease compared with healthy controls

The Kruskal-Wallis test showed significant differences between the two groups in 9 of 10 gait parameters: lateral sway of the head and COM were larger, the duration of the stance phase and double limb support time were longer, step width was wider, step length was shorter, step length variability was larger, step length ratio was smaller, and gait velocity was lower in patients with cerebellar diseases than in HCs. We did not find a significant difference in cadence. Post-hoc Mann-Whitney U tests revealed that DCD and CVD were significantly different from HCs on the 9 measures (Table 3).

Comparison between FW and HGW

1. Healthy controls

1.1 Qualitative assessment of body sway and forward progression (Fig. 2, 3)

1.1.1 Frontal image

In FW, the trajectories of the head and COM showed small V shapes (Fig. 2). The lower extremity and the trunk sidewall formed a straight line. In HGW, the arm holding the handkerchief was flexed at the elbow, and this arm and hand maintained a fixed position in relation to the trunk. The COM sway and the posture of the HAT segment were the same as those in FW.

1.1.2 Lateral image

In FW, the head and shoulder described a smooth, sinusoidal vertical displacement reflecting that of the trunk as the body moved forward, and the HAT segment made regular and rapid progress while maintaining an upright posture (Fig. 2). Similar results were seen in HGW.

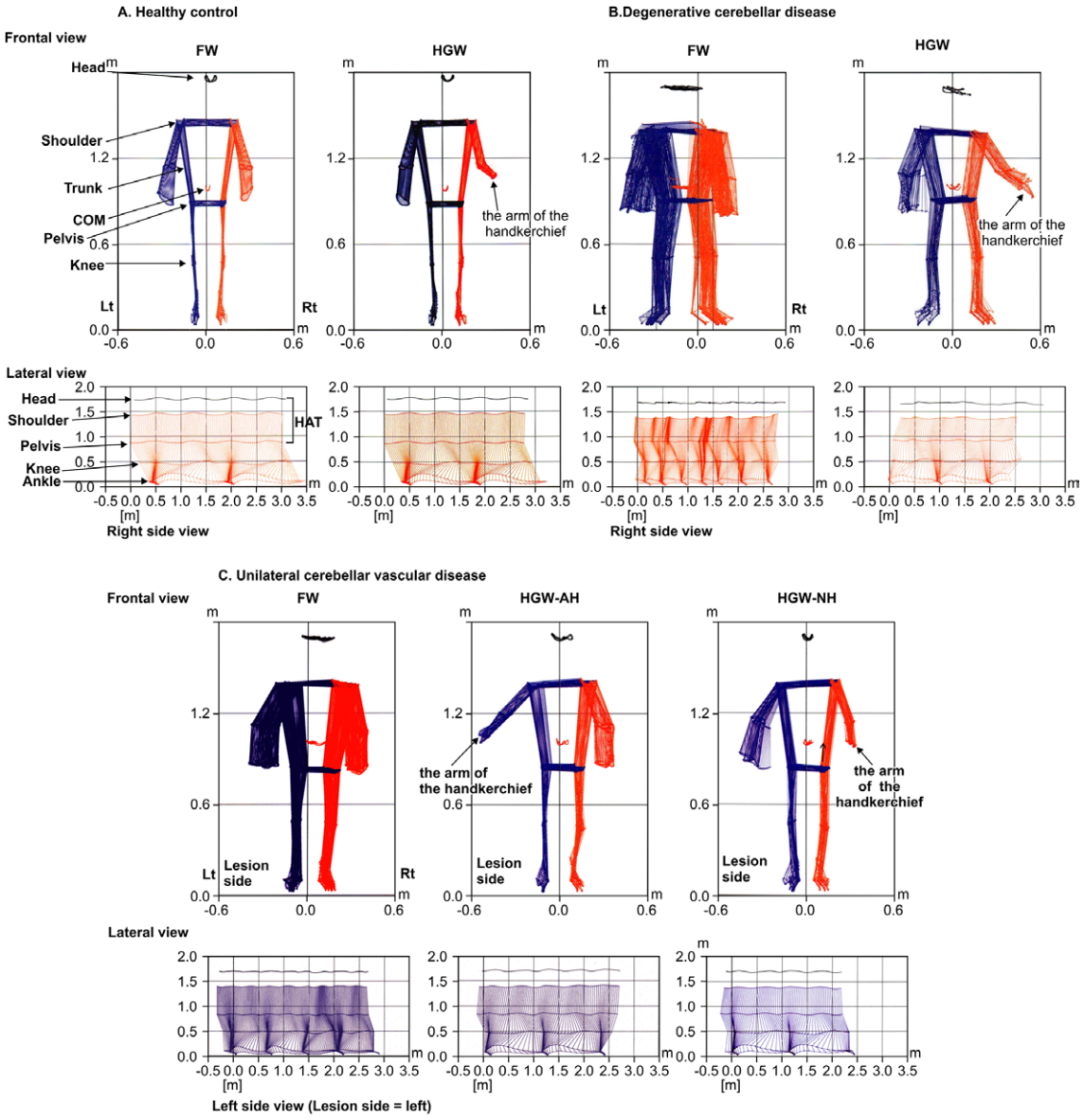

Fig. 2 Stick figures showing gait pattern viewed from the frontal and lateral plane.

A typical case of HC (A), DCD (B), and CVD (C) are demonstrated. The frontal images give the view from the rear of the subjects. Note that in a control subject (A), the head and the COM show small V-shapes in the frontal plane during both FW and HGW; the HAT segment is maintained in an upright posture and moves rapidly and regularly in the lateral plane during both FW and HGW. In patients with cerebellar disease (B, C), the head and the COM move erratically during FW and show great horizontal sway in the frontal plane; the HAT segment sways back and forth and progresses slowly and irregularly in the lateral plane. During HGW, HGW-AH, and -NH, the position of the arm and hand gripping the handkerchief is held constant, and the arm is immobilized with respect to the trunk, resulting in a decreased sway of the whole body and the COM in the frontal plane; HGW reduces the sway of the HAT segment, imparts a HAT posture that is closer to upright, and makes progression rapid and regular in the lateral plane. Refer to Table 1 for details on patient D7 and C6 with cerebellar disease. COM = center of mass, FW = free walking, HAT = head, arms, and trunk, HGW = handkerchief-guided walking, HGW-AH = handkerchief-guided walking with ataxic hand, HGW-NH = handkerchief-guided walking with normal hand.

1.1.3 Horizontal image

In FW, the COG trajectory described an approximately sinusoidal waveform in the plane of progression, passing outside or slightly within the medial border of the supporting foot (Fig. 3). The COP traveled from heel to toe almost in parallel with the COG trajectory. The COG and COP trajectories in HGW were similar to those in FW.

1.2 Quantitative assessment of gait parameters

We did not find significant differences in any gait parameters between FW and HGW in HCs (Fig. 4).

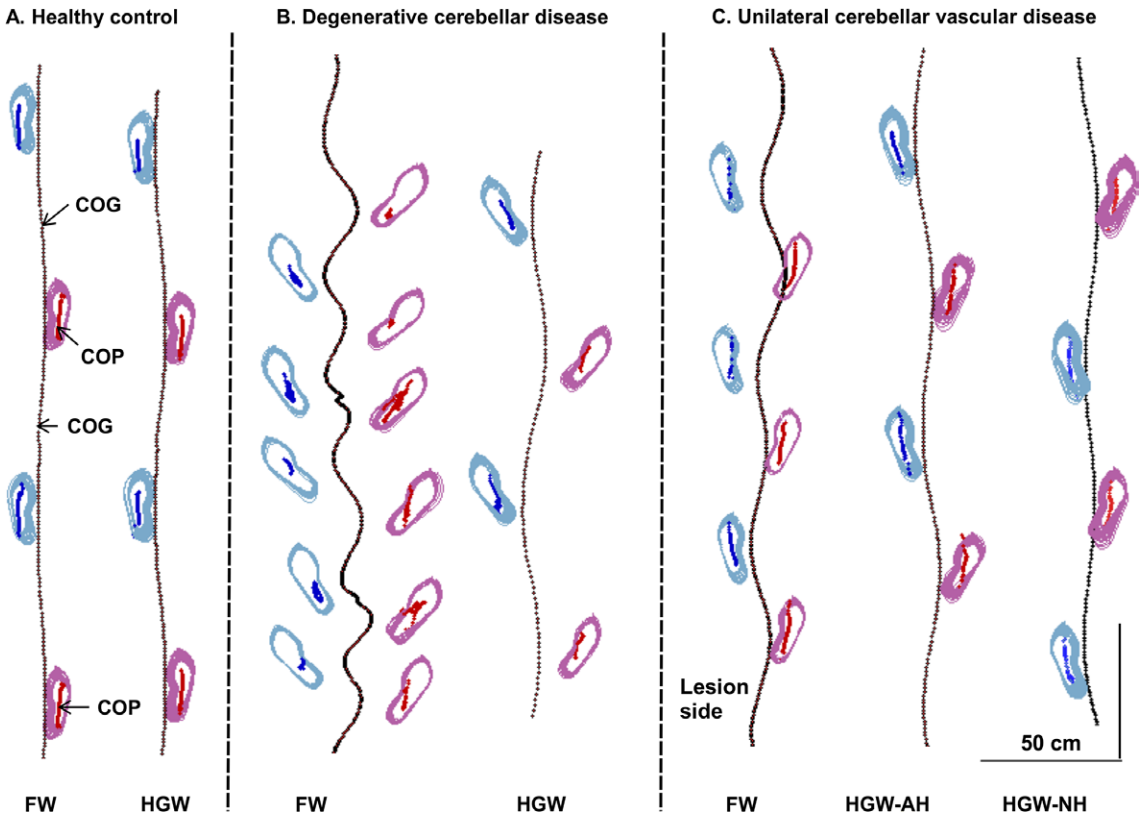

Fig. 3　Horizontal trajectories of the COG and COP relative to foot placements over one trial.
Representative of a typical HC (A), DCD (B), and CVD (C), the same cases as in Fig. 2. In a control subject (A), the COG passes outside or slightly within the medial border of the supporting foot and passes the midline of the plane of progression at the point of mid-double-support in walking. In a patient with DCD (B), the COG weaves tortuously and grossly, approaching the inside of the foot with every step during FW. The COG straightens out to become only mildly weaving during HGW. In a patient with CVD (C), the COG travels moderately tortuously during FW, mainly following the foot sole on the unaffected side, and away from the sole of the affected side. On HGW-AH and -NH, the COG advances mildly tortuously, contacting the heels of the soles on both sides. COG = center of gravity, COP = center of pressure, FW = free walking, HGW = handkerchief-guided walking, HGW-AH = handkerchief-guided walking with ataxic hand. HGW-NH = handkerchief-guided walking with normal hand.

2. Degenerative cerebellar disease

2.1 Qualitative assessment of body sway and forward progression (Fig. 2, 3)

2.1.1 Frontal image

In FW, the head and the COM showed large and irregular horizontal sway (Fig. 2). In HGW, the arm holding the handkerchief kept a fixed angle to the trunk, and as a result, the head and COM sway were attenuated markedly.

2.1.2 Lateral image

In FW, the head and shoulder showed vertical and irregular sway, and the HAT segment showed irregular and slow progress with moderate antero-posterior sway (Fig. 2). In HGW, the vertical movement of the head and shoulder became smooth, and the HAT segment took regular and large steps forward in an approximately upright posture.

2.1.3 Horizontal image

In FW, the COG trajectory was irregularly sinusoidal with large side-to-side amplitude, approaching the base of support at every step (Fig. 3). The COP trajectories had shapes of various forms and irregular lengths, different at every step. In HGW, the COG trajectory weaved less and tended to be straight. The COP tended to describe a straight line from heel to toe, in contrast with FW.

2.2 Quantitative assessment of gait parameters

HGW showed significant improvement compared with FW in 7 out of 10 gait parameters including lateral head sway, lateral COM sway, duration of stance phase, duration of double limb support time, gait velocity, step length, and cadence (Fig. 4). We did not find significant differences in three gait parameters: the step width, the step length variability, and the step length ratio, although the three parameters tended to be improved in HGW compared with FW.

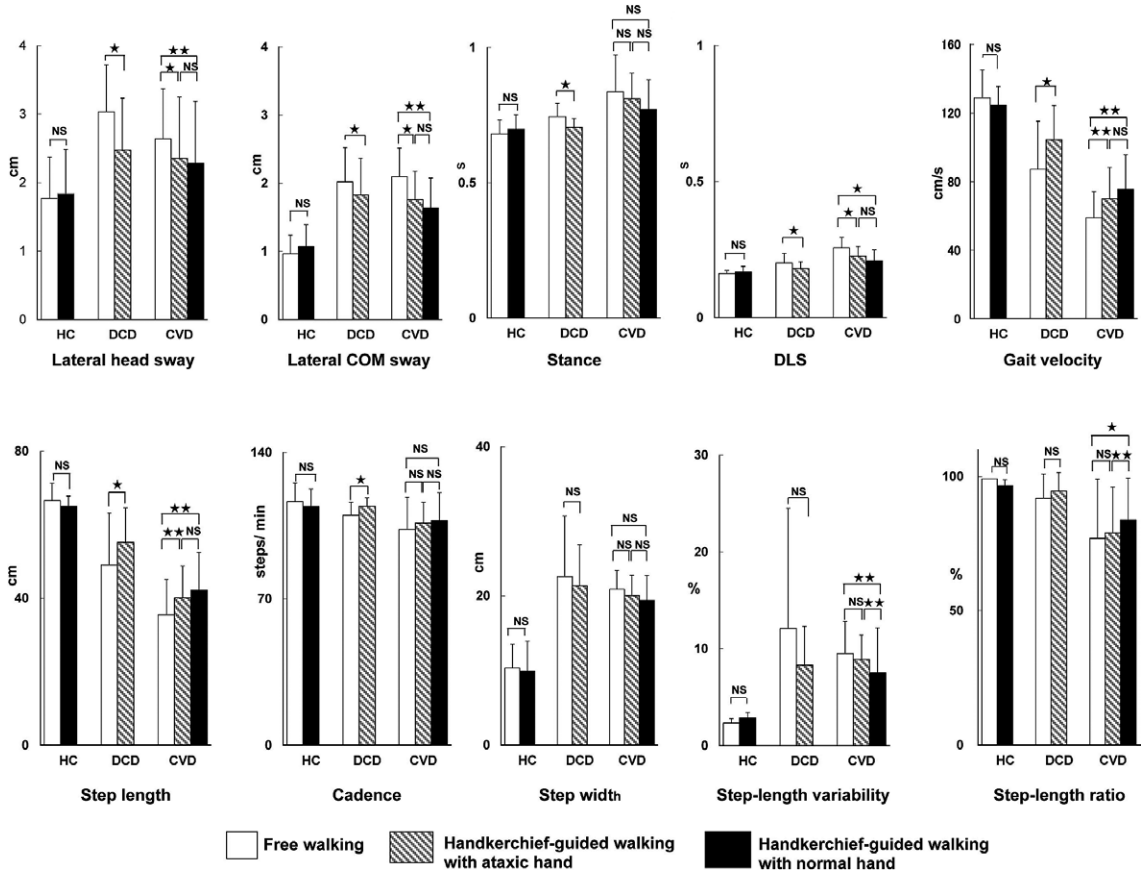

Fig. 4 Comparison of the gait parameters important for patients with cerebellar diseases with healthy controls.
The links between different bars represent significant differences. In both cerebellar groups (DCD and CVD), a considerable improvement in gait is seen in handkerchief-guided walking. In DCD, the HGW significantly improves seven parameters. In CVD, HGW with the affected hand improves five parameters, and HGW with the unaffected hand improves seven parameters. COM = center of mass: CVD = unilateral cerebellar vascular disease: DCD = degenerative cerebellar disease: DLS = double limb support time: HC = healthy controls: stance = stance phase. DCD; *, $P < 0.05$, CVD; **, $P < 0.05/3$; *, $P < 0.05$. NS = not significant.

Table 3 Free walking in patients with cerebellar disease compared with healthy controls.

	Gait parameters									
	Lateral head sway	Lateral COM sway	Stance	DLS	Gait velocity	Step length	Cadence	Step width	Step-length variability	Step-length ratio
DCD	0.002**	0.001**	0.038*	0.038*	0.004**	0.017*	0.165	0.001**	0.001**	0.011**
CVD	0.001**	0.001**	0.041*	0.001**	0.001**	0.001**	0.097	0.001**	0.001**	0.001**

For each combination of patient group and gait parameter, P values are given (Mann-Whitney U test). The parameters of the cerebellar groups show impairment relative to HCs during free walking. These include lateral body sway of head and COM, gait velocity, step length, step width, step-length variability, step-length ratio, stance phase, and double limb support time. We do not find a significant difference in cadence. COM = center of mass, CVD = unilateral cerebellar vascular disease, DCD = degenerative cerebellar disease, DLS = double limb support time, HC = healthy controls, stance = stance phase. Asterisks indicate significance. *, $P < 0.05$; **, $P < 0.05/3$.

3. Unilateral cerebellar vascular disease

3.1 Qualitative assessments of body sway and forward progression (Fig. 2, 3)

3.1.1 Frontal image

In FW, horizontal displacements of the head and the COM were large and irregular (Fig. 2). In HGW with the ataxic hand, the arm and hand grasping the handkerchief maintained an almost steady position in relation to the trunk, and the head and COM sway were attenuated. In HGW with the normal hand compared to HGW with the ataxic hand, the arm and hand

maintained a fixed position in relation to the trunk, and, accordingly, the head and COM sway were particularly attenuated, resulting in a small V-shaped trajectory.

3.1.2 Lateral image

In FW, the head and shoulder moved up and down slightly, and the HAT segment made irregular and slow progress with an approximately upright posture (Fig. 2). In HGW with the ataxic hand, vertical movement of the head and shoulder improved and became smooth, and the HAT segment took large and regular steps forward with a fixed ante-flexed posture. In HGW with the normal hand, vertical displacement of the head and shoulder were similarly improved as in HGW with the ataxic hand, but the HAT segment made forward progress more regularly and with a more nearly upright posture than in HGW with the ataxic hand.

3.1.3 Horizontal image

In FW, the COG trajectory weaved moderately, mainly following the foot sole of the unaffected side away from the affected side (Fig. 3). The COP traveled along either the middle or the inside of the foot sole on the affected side. In HGW with the ataxic hand, the COG trajectory weaved less than in FW, and was in contact with the foot sole (heel) bilaterally. The COP passed along a straight line in about the middle of the foot sole. In HGW with the normal hand, the COG and COP trajectories were almost the same as those in HGW with the ataxic hand.

3.2 Quantitative assessment of gait parameters

The Friedman test showed that there were significant differences among the three types of walking in 7 of 10 gait parameters: lateral head sway, lateral COM sway, double limb support time, gait velocity, step length, step length variability, and step length ratio (Fig. 4). Post-hoc Wilcoxon signed-rank tests revealed that HGW with the ataxic hand and with the normal hand were significantly different from FW for the first five of the seven measures: a decrease in lateral head sway, a reduction in lateral COM sway, an increase in gait velocity, an increase in step length, and shorter double limb support time (Fig. 4). These results led to a posture closer to upright during HGW. In addition, HGW with the normal hand as opposed to the ataxic hand revealed significant improvements in two measures compared with FW: a decrease in step-length variability, and an increase in the step-length ratio (Fig. 4). We did not find significant differences among the three walking types for the other three measures of gait: cadence, stance duration, and step width.

Discussion

Gait analysis revealed a larger lateral sway of the head and the COM, a longer duration of the stance phase and double-limb support time, shorter step length, greater step width, larger step length variability, smaller step length ratio, and a slower gait velocity in patients with cerebellar diseases as compared with the HCs. These results are compatible with previous studies[1)–4)].

This was the first study to show that ataxic gait is improved considerably by the handkerchief guide, a simple method. Quantitative gait analysis revealed an increased velocity, longer step length, decreased lateral sway of the head and COM, and shorter double limb support time. Qualitative analysis showed that the COG trajectory became more regular, smooth, and linear, staying within the medial borders of the supporting feet during level walking. These results indicated that upright posture had been stabilized in cases of cerebellar ataxic gait[18)]. From qualitative analysis of stick figures drawn from our data in the frontal plane, control of upright posture might be explained as the result of stabilization at a subconscious level of the arm and hand position in relation to the trunk and of the arm configuration.

A light touch on a rigid surface using the index finger has been reported to be useful for postural adjustments in normal subjects during standing and walking[5)–7)]. Two control mechanisms are involved in reducing postural sway: one is the tactile and proprioceptive afferent information from the arm and hand[19)20)], and the other is the constraint of the supra-postural task of holding the arm in constant light contact[12)]. Both mechanisms are likely to work to improve gait during use of the handkerchief guide. Nevertheless, two differences exist between the handkerchief guide and a light touch on a stationary surface. First, since the handkerchief is a stable point with an added predictable movement, a grip is preferred by most subjects to prevent the handkerchief from slipping from between the fingers during locomotion[21)22)]. Second, body sway could be reduced based on the information on the modulation of the force on the handkerchief induced by actual sway[23)]. In addition, two mechanisms may operate in HGW: one would be the handgrip facilitated mechanisms of inter-limb coordination subserving locomotor synergies[24)25)], and the other would be the interpersonal synchronization that occurs during side-by-side walking of the patient and caregiver[26)].

Using the HGW with the unaffected hand improved gait more than with the affected hand in patients with CVD. We interpreted this finding as resulting from more efficient maintenance of a fixed posture of the arm and hand in relation to the trunk with the unaffected hand than with the affected one. The cerebellum is supposed to play a role in the stabilization of the kinematic chain connecting the arm to the trunk. HC subjects did not show improvement of gait with the handkerchief guide. This could be explained by postulating a destabilization of upright posture by movements of the contact point due to the caregiver's sway[20)].

We use a handkerchief to improve ataxic gait. The folded handkerchief is a useful coupler for transmitting the pulling force from the patient to a caregiver during walking, while allowing

both vertical and back and forth movement. Holding hands can have the same effect as the handkerchief guide while the subject's arm is directly restricted by the caregiver. From the above, the handkerchief guide appears to be a simple and easy in way to assist a patient with cerebellar ataxia. This may be useful in gait training of cerebellar disease patients, because gait with the HGW is closer to FW than to direct-contact caregiver-assisted gait.

Acknowledgments: We would like to express our gratitude to Dr. Hitoshi Shinoto for comments on the manuscript, and to Dr. Yoshikazu Kyuma, Dr. Masao Murai, and Machiko Takahashi of the Nanasawa Rehabilitation Cerebrovascular Center, and to Drs Takamiti Kubokura, Yumi Miyazwa, and Kenji Ishihara of the Ushioda General Hospital for their support throughout the present study.

※ The authors declare there is no conflict of interest relevant to this article.

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