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Original Article

Relative and absolute reliability of gait variables obtained from gait analysis with trunk acceleration in community-dwelling individuals with chronic stroke: a pilot study

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Abstract. [Purpose] This pilot study aimed to investigate the relative and absolute reliability of variables obtained from an acceleration-based gait analysis conducted at comfortable and maximal gait speeds in individuals with chronic stroke. [Participants and Methods] This study included 25 community-dwelling individuals with chronic stroke. The participants wore triaxial accelerometers, while an observed walking trial was performed at comfortable and maximal speeds on two separate days 1 week apart. Relative reliability was evaluated using the intraclass correlation coefficient, and absolute reliability was evaluated using the Bland–Altman analysis, standard error of measurement, and minimal detectable change. [Results] The intraclass correlation coefficient of gait varied according to the acceleration-based gait analysis, ranging from 0.70 to 0.99. The Bland–Altman analysis revealed no systematic bias in both comfortable and maximal gait speed conditions. Most of the minimal detectable changes were smaller at maximal gait speed than at comfortable gait speed. [Conclusion] Acceleration-based gait analysis is a reliable method, particularly in maximal gait speed conditions. It may be used to assess the effect of rehabilitation interventions in individuals with chronic stroke.

Key words: Acceleration-based gait analysis, Chronic stroke, Reliability

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INTRODUCTION

Gait recovery is one of the major targets of rehabilitation programs for individuals with stroke, and hemiplegic gait has been the subject of research in developing gait analysis and rehabilitation methods[1]. Acceleration-based gait analysis (AGA) that measures trunk acceleration using triaxial accelerometers has recently been developed and is widely used in the clinical setting. Compared to three-dimensional motion analysis, which is the gold standard of movement analysis, AGA has the advantages of lower cost, ease of use, and no restrictions on the measurement environment. AGA can evaluate the stability,

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symmetry, and smoothness of gait, which are parameters that can discriminate patients with stroke from healthy individuals[2]. These parameters are also associated with the risk of falls[3], standing balance, and activities of daily living in stroke survivors[4]. Therefore, AGA assessment is a practical method to interpret the functional status in individuals with stroke, and it is necessary to verify the reliability, including relative and absolute reliability, of AGA in evaluating hemiparetic gait in daily clinical practice.

Relative reliability determines the degree of consistency among measurements, and intraclass correlation coefficients (ICCs) are often calculated. The intra-rater reliability based on the ICC of measurements obtained from AGA is higher in healthy[5, 6] and elderly individuals[7] as well as in elderly individuals at a risk of falling[8]. However, a limited study[9] has determined the intra-rater reliability of AGA in patients after stroke. Absolute reliability assesses the reliability of the evaluation or measurements by detecting the types and range of errors. The measured values may contain two types of error: systematic bias and random errors. The Bland–Altman analysis detects systematic bias in measurements. Identifying the standard error of measurement (SEM) and minimal detectable change (MDC) is a method to detect random errors in the measurements, and changes in those values can be interpreted as "true change" after treatment. Earlier studies have examined the absolute reliability of gait variables in AGA in healthy participants[10]. Despite reports on the absolute reliability of floor reaction force measurements[11], gait and balance assessments[12, 13], and gait variables measured on a treadmill in patients with stroke[14], no study has examined gait variables in AGA in such patients.

Furthermore, although many studies have demonstrated the reliability of AGA at comfortable gait speed, no studies have examined the reliability of AGA at maximal gait speed. It is important to demonstrate the reliability of AGA at maximal gait speed because maximal gait speed is kinematically and kinetically different from comfortable gait speed[15] and is often assessed in clinical settings among individuals with stroke[16, 17].

Thus, this pilot study aimed to investigate the relative and absolute reliability of gait variables measured by AGA at comfortable and maximal gait speeds in individuals with chronic stroke whose condition is considered stable and will not be affected by spontaneous recovery.

PARTICIPANTS AND METHODS

Community-dwelling individuals with post-stroke hemiplegia who participated in adult day care at Izumino, a geriatric health services facility, between October 2019 and March 2020 were recruited in this study. The inclusion criteria were as follows: (1) individuals who suffered from stroke before at least 6 months, (2) functional ambulation category (FAC)[18] >3, indicating the ability to walk without assistance regardless of prosthesis use, (3) no sign of cognitive dysfunction in terms of understanding instructions, (4) no orthopedic dysfunction that could affect walking, and (5) stable vital signs. The protocol of this cross-sectional observational study was approved by the Ethics Committees of Shinshu University (approval number: 4241) and Kakeyu Hospital (approval number: 2019010). Written informed consent was obtained from all participants. The study complied with the ethical standards of the Declaration of Helsinki 1964 and its subsequent revisions. Prior to the study, evaluation using Brunstrom recovery stages[19] in the lower extremity, FAC, the Berg Balance Scale[20], and the Barthel index score[21] was used to determine the participants' characteristics.

Gait assessments were performed on two separate days (days 1 and 2) 1 week apart at the same time by the same examiner (test–retest). For gait assessment, a triaxial accelerometer (Pocket IMU2, Gsport Ltd., Tokyo, Japan) was used.

The 10-m walking test (10-MWT) was performed to assess spatial and temporal gait parameters. The walking path was 16 m, which included acceleration and deceleration distances of 3 m each. The participants were instructed to walk 16 m at comfortable and maximal gait speeds. In this process, walking aids and/or orthoses were allowed to be used. Two walking conditions were randomly performed twice on each day; therefore, the participants underwent the walking test eight times over 2 days. Before starting the measurement, the participants walked twice along the walking path to familiarize themselves with the measurement. A belt for fall prevention was attached to the participant's trunk, and the examiner walked along with the participants without disturbing their performance. Gait speed was calculated using a handheld stopwatch at the 10-m mark of the walking path. Subsequently, the number of steps was calculated. For the analysis, the walking time (s), average stride length calculated from the walking time, and number of steps were used.

Gait analysis with a triaxial accelerometer was conducted simultaneously with the 10-MWT. The accelerometer was attached to the third lumbar vertebra to measure the acceleration in the anterior–posterior (AP), medial–lateral (ML), and vertical (VT) directions during walking. The sampling frequency was set to 100 Hz. The root mean square (RMS), autocorrelation coefficient (AC), and harmonic ratio (HR) were calculated from the AP, ML, and VT trunk accelerations obtained from the triaxial accelerometer. The RMS is the average magnitude of acceleration in each direction during walking and is considered an indicator of dynamic balance and smoothness of movement during walking[6]. In this study, the normalized RMS (nRMS), which excludes the effect of gait speed, was used[2]. The AC is defined as the regularity or symmetry of the steps or strides[22]; the closer it is to one, the more regular and symmetrical it is. Step and stride regularities were used in this study. HR is defined as the harmony or rhythmicity of gait[23]. The improved HR (iHR) was used in this study to show HR as a coefficient[24]. We performed subgroup analysis to confirm whether the use of walking aids influenced relative and absolute reliabilities among the participants. The participants were categorized into aid (walking with a walking aid) and without aid (walking without a walking aid) groups.

The Shapiro–Wilk test was used to confirm the normality of each index. Subsequently, we calculated the ICC (1,1) to evaluate the intra-rater reliability as the relative reliability. The obtained ICC were compared with Fleiss's criteria[25]. The Bland–Altman analysis was also performed to confirm absolute reliability, and the SEM, MDC, and relative MDC (MDC %) were calculated using the following equations:

$$SEM = SD \times \sqrt{(1 - ICC)}$$ [26]

$$MDC = SEM \times 1.96 \times \sqrt{2}$$ [26]

$$MDC\% = (MDC / mean) \times 100$$ [27]

The mean value used to calculate MDC% was the average of all variables in each measurement of two trials for the within-day reliability of day 1 and that of all variables in each measurement of one trial each of days 1 and 2 for the between-day reliability. All statistical analyses were performed using software R 4.02 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Forty community-dwelling individuals with stroke participated in adult day care during the study period. Twenty-five individuals who met the inclusion criteria were included in this study. The participant's age, height, and weight were 74.0 ± 6.6 years, 161.2 ± 9.4 cm, and 61.1 ± 10.7 kg, respectively. There were 16 participants in the aid group and nine participants in the without aid group. The participants' characteristics are presented in Table 1.

Table 2 shows the within-day results of day 1 for the gait variables obtained from AGA and 10-MWT. The within-day ICC of the comfortable gait speed condition was 0.80–0.98 in the overall cohort, 0.76–0.98 in the aid group, and 0.74–0.99 in the without aid group. The within-day ICC of the maximal gait speed condition was 0.81–0.99 in the overall cohort, 0.78–0.99 in the aid group, and 0.81–0.99 in the without aid group.

The Bland–Altman plots showed no systematic bias in the direction or distribution of test–retest errors for most variables. The within-day MDC (MDC%) of the comfortable gait speed condition was 0.06–25.20 (20.0–51.43%) in the overall cohort, 0.06–15.82 (22.45–50.00%) in the aid group, and 0.05–16.89 (13.85–48.28%) in the without aid group. The within-day MDC (MDC%) of the maximal gait speed condition was 0.06–12.50 (7.23–37.50%) in the overall cohort, 0.04–20.06 (5.00–34.73%) in the aid group, and 0.04–12.44 (11.24–31.03%) in the without aid group.

The between-day results of days 1 and 2 for the gait variables according to AGA and 10-MWT are presented in Table 3. The results showed that the within-day ICC of the comfortable gait speed condition was 0.73–0.98 in the overall cohort, 0.73–0.99 in the aid group, and 0.77–0.98 in the without aid group. The within-day ICC of the maximal gait speed condition was 0.70–0.99 in the overall cohort, 0.73–0.99 in the aid group, and 0.74–0.99 in the without aid group.

Table 1. Participants' characteristics

Variables	Data		
	Overall (n=25)	Aid (n=16)	Without aid (n=9)
Age, years; mean (SD), minimum–maximum	74.0 (6.6), 63–91	72.9 (6.7), 63–91	76.0 (6.1), 70–84
Gender			
Female/Male; n	9/16	4/12	5/4
Side of stroke			
Right/Left; n	12/13	9/7	6/3
Months since stroke; mean (SD), minimum–maximum	89.3 (72.3), 10–240	83.9 (74.1), 10–228	70.4 (72.6), 10–240
Walking Aids			
Single-point cane/Quad cane; n	13/3	13/3	none
Orthosis			
none/PAFO/AFO; n	10/12/3	7/1/9	6/1/2
Brunnstrom recovery stage			
III/IV/V; n	10/12/3	6/6/4	1/4/4
Functional Ambulation Categories			
3/4/5; n	10/12/3	9/6/1	3/2/4
Berg Balance Scale; mean (SD), minimum–maximum	42 (5.9), 36–54	43 (5.9), 36–54	44 (5.9), 36–54
Barthel index score; mean (SD), minimum–maximum	84.0 (10.1), 60–100	84.4 (10.9), 60–100	83.3 (9.0), 70–95

SD: standard deviation; PAFO: plastic ankle-foot orthosis; AFO: ankle-foot orthosis.

The Bland–Altman plots showed no systematic bias in the direction or distribution of test–retest errors for most variables. The between-day MDC (MDC%) of the comfortable gait speed condition was 0.08–17.00 (22.06–55.56%) in the overall cohort, 0.06–15.65 (24.00–50.00%) in the aid group, and 0.04–16.90 (13.85–46.51%) in the without aid group. The within-day MDC (MDC%) of the maximal gait speed condition was 0.07–12.70 (9.76–51.28%) in the overall cohort, 0.04–18.30 (5.06–38.10%) in the aid group, and 0.04–9.92 (7.95–31.25%) in the without aid group.

Table 2. Within-day intra-rater reliability at comfortable and maximal gait speed on day 1

			Comfortable gait speed						Maximal gait speed					
			Mean (SD)	ICC (1,1)	CI (95%)	SEM	MDC	MDC%	Mean (SD)	ICC (1,1)	CI (95%)	SEM	MDC	MDC%
Gait speed (m/s)		Overall	0.60 (0.23)	0.98	0.95–0.99	0.01	0.13	21.67	0.83 (0.29)	0.99	0.97–0.99	0.02	0.06	7.23
		Aid	0.57 (0.23)	0.97	0.93–0.99	0.02	0.15	26.32	0.80 (0.31)	0.99	0.98–0.99	0.01	0.04	5.00
		Without aid	0.65 (0.21)	0.98	0.91–0.99	0.01	0.09	13.85	0.89 (0.24)	0.98	0.93–0.99	0.02	0.10	11.24
nRMS (g)	AP	Overall	0.34 (0.37)	0.98	0.95–0.99	0.06	0.16	47.06	0.27 (0.32)	0.99	0.98–0.99	0.03	0.07	25.93
		Aid	0.38 (0.47)	0.98	0.94–0.99	0.02	0.19	50.00	0.30 (0.36)	0.99	0.98–0.99	0.01	0.07	23.33
		Without aid	0.29 (0.20)	0.99	0.96–0.99	0.01	0.05	17.24	0.18 (0.09)	0.96	0.83–0.99	0.02	0.04	22.22
	ML	Overall	0.26 (0.14)	0.98	0.96–0.99	0.02	0.06	23.08	0.32 (0.21)	0.97	0.93–0.99	0.04	0.11	34.38
		Aid	0.25 (0.13)	0.97	0.92–0.98	0.01	0.06	24.00	0.35 (0.23)	0.97	0.94–0.99	0.01	0.10	28.57
		Without aid	0.29 (0.16)	0.91	0.67–0.98	0.02	0.14	48.28	0.28 (0.18)	0.99	0.97–0.99	0.01	0.04	14.29
	VT	Overall	0.69 (0.49)	0.97	0.92–0.99	0.09	0.25	36.23	0.80 (0.34)	0.98	0.95–0.99	0.05	0.13	16.25
		Aid	0.81 (0.48)	0.95	0.87–0.98	0.04	0.31	38.27	0.86 (0.32)	0.98	0.95–0.99	0.01	0.12	13.95
		Without aid	0.45 (0.34)	0.96	0.84–0.97	0.03	0.19	42.22	0.66 (0.37)	0.98	0.91–0.99	0.02	0.13	19.70
AC Step regularity	AP	Overall	0.43 (0.15)	0.92	0.83–0.96	0.01	0.10	23.26	0.44 (0.14)	0.91	0.81–0.96	0.01	0.13	29.55
		Aid	0.38 (0.14)	0.90	0.75–0.96	0.02	0.13	34.21	0.39 (0.14)	0.94	0.85–0.98	0.01	0.10	25.64
		Without aid	0.55 (0.13)	0.87	0.42–0.97	0.03	0.18	32.73	0.55 (0.11)	0.89	0.58–0.98	0.02	0.11	20.00
	ML	Overall	0.39 (0.14)	0.82	0.63–0.92	0.01	0.14	35.90	0.39 (0.16)	0.92	0.85–0.97	0.01	0.09	23.08
		Aid	0.36 (0.12)	0.85	0.57–0.95	0.02	0.16	44.44	0.36 (0.15)	0.97	0.94–0.99	0.01	0.06	16.67
		Without aid	0.43 (0.14)	0.86	0.48–0.96	0.04	0.20	46.51	0.48 (0.15)	0.94	0.75–0.93	0.02	0.11	22.92
	VT	Overall	0.35 (0.14)	0.80	0.60–0.91	0.01	0.18	51.43	0.40 (0.16)	0.89	0.74–0.95	0.02	0.15	37.50
		Aid	0.32 (0.11)	0.87	0.67–0.95	0.01	0.11	34.38	0.38 (0.19)	0.89	0.70–0.96	0.01	0.10	26.32
		Without aid	0.43 (0.17)	0.86	0.48–0.96	0.04	0.20	46.51	0.52 (0.11)	0.94	0.78–0.94	0.01	0.08	15.38
AC Stride regularity	AP	Overall	0.51 (0.13)	0.89	0.77–0.95	0.02	0.15	29.41	0.53 (0.14)	0.94	0.88–0.98	0.01	0.10	18.87
		Aid	0.49 (0.15)	0.96	0.83–0.99	0.02	0.11	22.45	0.49 (0.12)	0.94	0.85–0.98	0.01	0.08	16.33
		Without aid	0.57 (0.14)	0.88	0.56–0.98	0.01	0.08	14.04	0.56 (0.19)	0.88	0.69–0.95	0.02	0.15	26.79
	ML	Overall	0.45 (0.15)	0.86	0.78–0.97	0.02	0.09	20.00	0.47 (0.13)	0.96	0.93–0.99	0.01	0.08	17.02
		Aid	0.42 (0.11)	0.95	0.87–0.98	0.03	0.15	35.71	0.46 (0.13)	0.93	0.81–0.97	0.01	0.10	21.74
		Without aid	0.50 (0.16)	0.92	0.68–0.98	0.02	0.12	24.00	0.50 (0.13)	0.94	0.76–0.99	0.01	0.07	14.00
	VT	Overall	0.47 (0.11)	0.87	0.65–0.95	0.01	0.14	29.79	0.52 (0.12)	0.97	0.95–0.97	0.01	0.06	11.54
		Aid	0.44 (0.09)	0.82	0.58–0.93	0.01	0.11	25.00	0.49 (0.10)	0.82	0.56–0.93	0.02	0.13	26.53
		Without aid	0.52 (0.13)	0.85	0.32–0.96	0.03	0.19	36.54	0.58 (0.13)	0.85	0.30–0.96	0.03	0.18	31.03
iHR	AP	Overall	59.80 (12.80)	0.88	0.75–0.95	1.34	12.90	21.57	58.40 (8.10)	0.90	0.78–0.95	0.94	9.00	15.41
		Aid	54.58 (11.35)	0.84	0.60–0.93	1.68	13.17	24.13	59.04 (10.75)	0.88	0.70–0.96	1.28	10.06	17.04
		Without aid	63.30 (11.76)	0.92	0.69–0.98	1.78	9.86	15.58	57.21 (9.51)	0.93	0.75–0.98	1.28	7.01	12.25
	ML	Overall	55.70 (12.60)	0.80	0.60–0.91	2.62	25.20	45.24	54.20 (8.20)	0.81	0.60–0.91	1.30	12.50	23.06
		Aid	51.78 (11.16)	0.76	0.46–0.91	1.99	15.65	30.22	57.76 (12.06)	0.78	0.38–0.91	2.55	20.06	34.73
		Without aid	61.69 (12.05)	0.78	0.29–0.95	3.04	16.89	27.38	57.49 (7.62)	0.81	0.30–0.95	2.24	12.44	21.64
	VT	Overall	59.80 (11.50)	0.81	0.62–0.91	1.60	15.30	25.59	60.40 (10.50)	0.87	0.73–0.90	1.10	10.60	17.55
		Aid	55.16 (10.37)	0.79	0.50–0.92	2.01	15.82	28.68	57.38.40 (9.53)	0.83	0.59–0.93	1.54	12.09	21.07
		Without aid	63.74 (11.87)	0.74	0.20–0.94	2.76	15.30	24.00	60.71 (11.86)	0.92	0.68–0.98	1.78	9.92	16.34

SD: standard deviation; ICC: intraclass correlation coefficient; SEM: standard error of measurement; CI (95%): 95% confidence interval; MDC: minimal detectable change 95%; MDC%: relative MDC; nRMS: normalized root mean square; AC: autocorrelation coefficient; iHR: improved harmonic ratio; AP: anterior-posterior; ML: medial-lateral; VT: vertical; Aid: Aid group; Without aid: Without aid group.

DISCUSSION

In this pilot study, we examined the relative and absolute reliability of gait variables according to AGA in individuals with chronic stroke at comfortable and maximal gait speeds. The relative reliability of AGA measurements was confirmed to be at a certain high level. In the absolute reliability analysis, no systematic bias of measurements obtained from AGA was

Table 3. Between-day intra-rater reliability at comfortable and maximal gait speed across day 1 and day 2

			Comfortable gait speed						Maximal gait speed					
			Mean (SD)	ICC (1,1)	CI (95%)	SEM	MDC	MDC%	Mean (SD)	ICC (1,1)	CI (95%)	SEM	MDC	MDC%
Gait speed (m/s)		Overall	0.62 (0.21)	0.96	0.91–0.99	0.05	0.14	22.58	0.82 (0.29)	0.98	0.96–0.99	0.03	0.08	9.76
		Aid	0.57 (0.23)	0.97	0.93–0.99	0.02	0.14	24.56	0.79 (0.31)	0.99	0.98–0.99	0.01	0.04	5.06
		Without aid	0.65 (0.21)	0.98	0.91–0.99	0.02	0.09	13.85	0.88 (0.24)	0.98	0.95–0.99	0.01	0.07	7.95
nRMS (g)	AP	Overall	0.33 (0.30)	0.98	0.95–0.97	0.03	0.09	27.27	0.27 (0.29)	0.99	0.98– 0.99	0.03	0.07	25.93
		Aid	0.38 (0.47)	0.98	0.94–0.99	0.02	0.19	50.00	0.32 (0.36)	0.99	0.98–0.99	0.01	0.07	21.88
		Without aid	0.18 (0.09)	0.96	0.84–0.99	0.01	0.04	22.22	0.29 (0.20)	0.99	0.96–0.99	0.01	0.05	17.24
	ML	Overall	0.28 (0.19)	0.98	0.94–0.99	0.03	0.08	28.57	0.32 (0.22)	0.97	0.93–0.99	0.04	0.11	34.38
		Aid	0.25 (0.13)	0.99	0.92–0.99	0.01	0.06	24.00	0.34 (0.23)	0.97	0.94–0.99	0.01	0.04	11.76
		Without aid	0.28 (0.15)	0.95	0.81–0.99	0.02	0.10	35.71	0.28 (0.18)	0.99	0.97–0.99	0.01	0.04	14.29
	VT	Overall	0.68 (0.41)	0.98	0.95–0.99	0.06	0.15	22.06	0.78 (0.34)	0.98	0.95–0.99	0.05	0.13	16.67
		Aid	0.81 (0.48)	0.95	0.86–0.98	0.04	0.30	37.04	0.84 (0.31)	0.96	0.89–0.98	0.02	0.17	20.24
		Without aid	0.45 (0.34)	0.96	0.84–0.99	0.04	0.19	42.22	0.66 (0.37)	0.98	0.92–0.97	0.02	0.13	19.70
AC	AP	Overall	0.40 (0.18)	0.83	0.65–0.92	0.02	0.17	42.50	0.45 (0.15)	0.86	0.71–0.94	0.02	0.15	33.33
Step regularity		Aid	0.38 (0.14)	0.90	0.74–0.96	0.02	0.13	34.21	0.40 (0.14)	0.90	0.75–0.96	0.02	0.12	30.00
		Without aid	0.55 (0.13)	0.87	0.42–0.97	0.03	0.18	32.73	0.54 (0.10)	0.90	0.62–0.98	0.02	0.09	16.67
	ML	Overall	0.36 (0.13)	0.76	0.52–0.89	0.02	0.20	55.56	0.39 (0.18)	0.70	0.43–0.86	0.02	0.20	51.28
		Aid	0.35 (0.15)	0.86	0.48–0.93	0.03	0.15	42.86	0.36 (0.12)	0.95	0.87–0.98	0.01	0.08	22.22
		Without aid	0.43 (0.15)	0.92	0.68–0.98	0.02	0.12	27.91	0.48 (0.16)	0.92	0.69–0.98	0.02	0.13	27.08
	VT	Overall	0.34 (0.15)	0.82	0.59–0.92	0.02	0.18	52.94	0.40 (0.18)	0.88	0.75–0.95	0.01	0.10	25.00
		Aid	0.32 (0.11)	0.87	0.67–0.95	0.01	0.11	34.38	0.35 (0.15)	0.87	0.50–0.97	0.01	0.09	25.71
		Without aid	0.43 (0.17)	0.85	0.48–0.99	0.04	0.20	46.51	0.48 (0.16)	0.86	0.48–0.93	0.03	0.15	31.25
AC	AP	Overall	0.49 (0.17)	0.81	0.61–0.91	0.02	0.20	40.82	0.53 (0.14)	0.92	0.83–0.96	0.01	0.11	20.75
Stride regularity		Aid	0.49 (0.14)	0.89	0.73–0.96	0.02	0.13	26.53	0.49 (0.12)	0.94	0.85–0.98	0.01	0.08	16.33
		Without aid	0.57 (0.14)	0.88	0.56–0.97	0.03	0.14	24.56	0.60 (0.10)	0.79	0.64–0.95	0.03	0.15	25.00
	ML	Overall	0.46 (0.15)	0.79	0.58–0.90	0.02	0.17	36.96	0.48 (0.14)	0.87	0.74–0.91	0.02	0.16	33.33
		Aid	0.46 (0.12)	0.73	0.24–0.90	0.03	0.22	47.83	0.42 (0.11)	0.84	0.57–0.94	0.02	0.16	38.10
		Without aid	0.46 (0.17)	0.88	0.57–0.97	0.02	0.16	34.78	0.51 (0.15)	0.86	0.50–0.97	0.03	0.14	27.45
	VT	Overall	0.44 (0.13)	0.87	0.73–0.94	0.02	0.14	31.82	0.49 (0.12)	0.94	0.87–0.97	0.04	0.11	22.45
		Aid	0.44 (0.09)	0.82	0.57–0.93	0.01	0.11	25.00	0.48 (0.11)	0.80	0.54–0.93	0.01	0.12	25.00
		Without aid	0.52 (0.13)	0.85	0.32–0.96	0.03	0.19	36.54	0.56 (0.12)	0.98	0.91–0.99	0.01	0.05	8.93
iHR	AP	Overall	59.40 (12.00)	0.84	0.68–0.93	1.49	14.30	24.07	57.20 (7.70)	0.86	0.72–0.94	0.82	7.88	13.78
		Aid	54.58 (11.35)	0.98	0.94–0.99	1.68	13.20	24.18	56.99 (10.31)	0.81	0.48–0.93	1.81	14.17	24.86
		Without aid	63.30 (11.76)	0.92	0.70–0.98	1.78	9.87	15.59	59.44 (6.21)	0.80	0.33–0.95	1.50	8.44	14.20
	ML	Overall	57.20 (10.70)	0.73	0.47–0.87	1.77	17.00	29.72	53.70 (9.60)	0.74	0.50–0.88	1.32	12.70	23.65
		Aid	51.78 (11.16)	0.86	0.63–0.95	1.99	15.65	30.22	57.30 (12.34)	0.73	0.39–0.89	2.33	18.30	31.94
		Without aid	61.69 (12.04)	0.87	0.44–0.97	3.04	16.90	27.40	56.64 (9.06)	0.74	0.20–0.94	1.74	9.62	16.98
	VT	Overall	58.90 (12.50)	0.81	0.73–0.95	1.52	14.60	24.79	57.80 (9.40)	0.84	0.68–0.93	1.03	9.89	17.11
		Aid	58.00 (11.10)	0.81	0.47–0.93	1.93	15.16	26.14	55.16 (10.37)	0.83	0.59–0.93	1.54	12.09	21.92
		Without aid	59.99 (8.91)	0.77	0.28–0.95	2.22	12.30	20.50	63.74 (11.87)	0.92	0.68–0.98	1.78	9.92	15.56

SD: standard deviation; ICC: intraclass correlation coefficient; SEM: standard error of measurement; CI (95%): 95% confidence interval; MDC: minimal detectable change 95%; MDC%: relative MDC; nRMS: normalized root mean square; AC: autocorrelation coefficient; iHR: improved harmonic ratio; AP: anterior-posterior; ML: medial-lateral; VT: vertical; Aid: Aid group; Without aid: Without aid group.

confirmed, and MDCs were small under maximal gait speed conditions. To the best of our knowledge, this is the first study to determine the reliability of AGA measurements in individuals with chronic stroke at comfortable and maximal gait speeds.

Our results revealed that the ICCs ranged from 0.70 to 0.99 regardless of whether walking aid was used at comfortable and maximum speed conditions. However, the reliability of the variables in the ML direction was slightly lower than those in the other directions. This was attributed to the influence of pelvic rotation and the fact that the floor reaction force was smaller in the ML direction than in the other directions[10]. However, the ICC value was >0.7 even in the ML direction. Therefore, our results indicate that the relative reliability of AGA in participants after stroke may be used in daily clinical practice. Previous studies have reported that the ICC of measurements obtained from AGA (nRMS and AC) were high among healthy[5, 6] and elderly adults[7] as well as among elderly adults at a risk of falling[8]. It was also reported in individuals with chronic stroke[9], confirming our findings. In the aforementioned studies, various walking paths were used, ranging from 4.88 m to 20.0 m[4–7], and the ICC tended to be high when the walking path became longer. In this study, the analysis was conducted using the 10-MWT, which has a relatively longer pathway based on previous studies, considering its clinical application. These conditions might have contributed to the high ICC values observed in this study and, therefore, the distance of 10 m was sufficient in obtaining reliability results for gait analysis from AGA in individuals with chronic stroke.

We also determined the absolute reliability of AGA in community-dwelling individuals with chronic stroke. Our results revealed no systematic bias in the AGA measurements, and this assessment is considered reliable. We found that MDCs in such patients were larger than those in healthy individuals[9]. This might be attributed to the fact that individuals with stroke have different kinematic and kinetic gait patterns and walking strategies than those of healthy individuals. Compared to healthy participants, stroke survivors have specific spatiotemporal gait patterns, including reduced cadence, prolonged free leg time on the hemiplegic side, prolonged stance time on the non-hemiplegic side, and asymmetry in stride length[28, 29]. In addition, Mizuike et al.[2] revealed larger variability in raw RMS, nRMS, and AC values in stroke survivors compared to those in healthy individuals. These results suggest that there are individual differences in gait patterns and a large variability in compensatory strategies in individuals with stroke.

Compared to the comfortable walking speed condition, the maximum walking speed condition showed higher ICCs and smaller MDC and MDC% for many variables regardless of walking aid use. Earlier studies that determined the MDCs of gait speeds[13, 30] have revealed that MDCs or MDC% are smaller at maximal gait speed than at comfortable speed in stroke survivors. The MDC% of both swing and stance time in individuals with chronic stroke are smaller at maximal gait speed than at comfortable gait speed[31]. Wang et al.[32] revealed that the coefficients of variation of gait parameters, such as stride length, stance time, swing time, and double support phase, decreased with increasing treadmill speeds in patients with chronic stroke and healthy individuals. These studies suggest that maximal gait speed, a challenging task for individuals with stroke, reduces the variability of gait patterns and compensatory strategies. Therefore, the results of these studies may support our findings concerning the ICCs and MDCs of AGA variables. Our findings indicate that AGA, especially at the maximal gait speed, is a reliable method for assessing gait disability in individuals with chronic stroke and can be used to assess the effects of rehabilitation intervention on hemiplegic gait.

We also performed subgroup analysis to confirm the reliability of the gait variables with and without walking aids. Although the gait variables and participant characteristics from AGA in this study showed that the aid group had lower gait ability than the without aid group, the ICC was >0.7 for all variables, and no consistent trend was observed between the aid and without aid group in terms of differences in ICC and MDC. Kuan et al.[33] have reported that the use of walking aids increases gait stability in patients with stroke, reduces the risk of falls, and improves independent walking. Their study indicate that the use of walking aids may also increase the reliability of gait, even in stroke survivors with low gait ability.

This study has some limitations. First, our study sample size was small because of the pilot study design. Therefore, we could not stratify participants by walking speed and/or walking ability, which influences the ICC value of gait-related variables among participants with chronic stroke[31]. Although we categorized the participants into the aid and without aid groups, the range of 95% confidence intervals in gait variables was wide. A study with a larger sample size is needed to clarify the influence of gait abilities on the reliability of AGA based on the results of this study. Second, our targeted population included individuals in the chronic phase of stroke, and our results might differ from those in individuals in the other phases of stroke as a previous study[1] revealed that the gait variables obtained from AGA in patients after stroke changed with recovery of voluntary movements. However, as a certain degree of reliability was obtained in ambulatory individuals with stroke in this study, AGA may be used for within-day gait assessment, which is not affected by spontaneous recovery, regardless of the phases of stroke. Therefore, future studies should investigate the reliability at any recovery stage. Finally, we determined the intra-rater reliability, but not the inter-rater reliability. Thus, inter-rater reliability should be examined in future studies.

In conclusion, the relative and absolute reliability of AGA among individuals with chronic stroke were confirmed. Measurement at maximal walking speed may be more reliable in AGA in individuals with chronic stroke. The findings of our pilot study can be basis for future studies with a larger sample size.

Funding and Conflict of Interest

None.

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