Original Investigation

Variability of Walking in Able-Bodied Adults Across Different Time Intervals

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ABSTRACT

This study aimed to quantify the variability of walking in young adults across measurement sessions held at varied time intervals. Inconsistent marker placement, a major source of variation in gait measurement, was minimized in this study in order to quantify how much variation is attributable to participants naturally altering their walking. Three-dimensional gait data were captured from five young adults on four sessions on each of four days. After Day 1, marker locations were identified with permanent pen to minimise variance due to inconsistent marker placement. A multi-level linear regression model was used to estimate inter-trial and inter-session variance for two hour, within-day, across-a-day and across-a-week intervals. Inter-trial variation was relatively constant within sessions and ranged from a standard deviation (SD) of 0.7 degrees to 2.5 degrees. Inter-session variation differed across gait variables and time intervals, with a maximum variation of 2.4 degrees (hip rotation, across a week). Young adults varied their kinematic walking patterns (SD = 1-2 degrees) over intervals of 2 hours to 1 week. In reliability studies, variations of this magnitude may simply reflect natural or 'intrinsic' human variation rather than marker placement error.

Keywords: Gait, rehabilitation, variability

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Introduction

Kinematic data from three-dimensional gait analysis (3DGA) has a key role in movement analysis in the biomedical and sport sciences. Within clinical gait analysis services for patients with gait disability, repeated measurements are commonly used to monitor change over time and to evaluate the response to interventions such as orthopedic surgery, physical therapy, medications and orthotics. Within sport sciences, repeated measures may examine the effect of altered training techniques or recovery from injury. Studies of repeatability are widely advocated as part of quality assurance or accreditation procedures in motion analysis laboratories, occurring in both biomedical and sports contexts (e.g. Commission for Motion Laboratory Accreditation, Inc.). An understanding of the sources and magnitude of typical variation or error associated with such repeated data is an important consideration during data interpretation.

Prior research has shown that kinematic data from repeated 3DGA of an individual shows variation between sessions [1]. Several reports have suggested that inconsistent marker placement is a major contributor to inter-session variation and that such variation equates to human error in the marker placement and measurement process [2-4]. However, very few studies have focused on quantifying all of the sources of variation that may contribute to inter-session variance. In particular, little attention has focussed on how 'natural' variation in walking between sessions may contribute to data variation. It seems likely that a component of inter-session variation may also be due simply to small "natural" variation in participant walking.

An individual's walking pattern may vary over very short intervals (i.e., 'inter-trial'variation within a session) or over longer intervals of hours, days or weeks (i.e 'inter-session'). Two prior reports examined the contribution of natural or 'intrinsic' variation in walking across repeated measurement sessions by marking the location of markers to enable consistent placement [3, 5]. These studies reported natural variation ranging up to 2.3°. These studies, however, examined only a single time interval. Prior 3DGA repeatability studies have selected a wide variety of time intervals ranging from two hours [6] to 20 weeks [7]. The time frames most commonly used included within-a-day, [6, 8, 9] days within-a-week [5, 10, 11] or a week or longer [7, 12]. Quantification of typical natural inter-session variation over a range of time frames may provide insight into the optimal design and interpretation of data from conventional reliability studies, where markers are replaced and data captured over intervals. This study aimed to quantify the within-session and inter-session natural variability of walking in young adults; within-a-day, across-a-day and across-a-week, whilst minimising error due to inconsistent marker placement.

Methods

Five adults (three females, two males, age range from 21-33 years, mean BMI 23.5), with no prior conditions affecting gait, provided consent after study approval from the University of Melbourne Human Research Ethics Committee.

Each participant attended a gait laboratory on four days; two consecutive weekdays and the same two consecutive days one week later. On the first day, anthropometric parameters required for a conventional biomechanical model (Plug-in-gait; PiG, with physiotherapist with 6 years experience with gait analysis. A knee alignment device was used for a calibration trial and data acquired using a VICON (Oxford Metrics) 6camera system (120Hz). For each participant, a static calibration was performed in the first session, and applied to all subsequent sessions.

On each of four test days, data were captured in four sessions approximately two hours apart. Participants walked at their self-selected speed. At the end of Day One, markers were removed, and a permanent pen used to mark the skin at each marker location. These markings were used to direct marker placement on subsequent days.

Within each session, after two 'practice walks', the next five sequential trials were selected for analysis. Separate three-level linear regression models were used for each kinematic gait variable and included random effects for participant, session, and trial (residual) [14]. Effects were "averaged" across the gait cycle by including all times of data capture across the gait cycle and incorporating a fixed effect for time into the model. The parameters of most interest were the variances of the random effects for session and trial and we present maximum likelihood estimates of this variation expressed as standard deviations. The statistical analysis was performed using the xtmixed command in Stata Release 10 (StataCorp LP, College Station, TX).

Results

Across all sessions and participants, the mean walking speed was 1.39 m/s (SD: 0.13); stride length was 1.40 m (SD: 0.07), and cadence was 118.9 steps/min (SD: 6.9). The was relatively constant within sessions. Inter-session variation remained generally low; SD values were equal or less than 0.05 m/s (speed), 2 steps/min (cadence) and 0.03 m (stride length).

Inter-trial and inter-session variations of the kinematic data are presented in Table 1 and Table 2 respectively. Inter-trial variability remained relatively constant across intervals but differed across variables, with the highest values for knee flexion and hip rotation. Inter-session variation remained generally low, with SD values typically less than two degrees, the smallest variation occurring in pelvic obliquity, hip abduction and pelvic rotation, and the largest in hip rotation. A trend was evident for small increases in inter-session variation with increasing

Table 1. Spatio-temporal variation (SD) across intervals.

		Within 2 hours	Within a day	Across a day	Across a week
Speed (m/s)	Inter-trial SD	.038	.040	.036	.039
	Inter-session SD	.029	.018	.034	.050
Cadence (steps/min)	Inter-trial SD	2.02	2.11	2.05	2.05
	Inter-session SD	2.70	1.26	2.41	2.44
Stride Length (m)	Inter-trial SD	.031	.032	.030	.029
	Inter-session SD	.017	.021	.023	.030

time between sessions. Figure 1 also illustrates the total variation across intervals, varying from approximately 1 to 3 degrees.

Discussion

This study quantifies variation in the walking patterns of young adults, across intervals of up to one week. With a conventional gait model, inter-session variation of around 1-2 degrees (SD) may be due to natural variation in walking and not necessarily reflect error due to marker placement. Other measurement system related sources of variation may also theoretically contribute, although properly configured and calibrated systems are generally considered to add negligible variation [3]. Our findings are within 1 degree of the SD values reported by Gorton et al. [3], and the standard error values reported by Eve et al. [5] but our results also extend this knowledge to a greater range of time intervals and gait variables.

These results may assist with the selection of time intervals for future reliability studies.. Although short intervals of less than a day are often logistically easier to organise, they are also more susceptible to the distinct possibility that assessors may recall aspects of the anthropometric measures or subject-specific marker location. Fatigue may also cause true variation in participants with gait pathology when measured repeatedly. No large differences were seen across time intervals of two hours to one week in healthy participants. Intervals of days or a week may therefore be more appropriate in reliability studies, to minimize potential assessor bias without introducing greater inter-session variation.

A limitation of our study is that very small differences in marker placement may have occurred between sessions over days and contributed to inter-session variability. Our values therefore may be a slight over-estimate of the true amount of inter-session variability that can be attributed to "natural" variability. In typical studies of 3DGA reliability with marker replacement between sessions, variation above the values reported here can be more confidently considered to reflect procedural error, such as marker placement inconsistency. Furthermore, this study chose a small and convenient young healthy adult sample to provide pilot data for a further definitive study. The results should not be directly applied to other groups, particularly clinical populations, without careful consideration of the influence of the pathology-related impairments such as spasticity, fatigue, selective motor control and cooperation. It does seem likely however, that people with gait pathology will not show lower levels of variation between sessions than young healthy adults.

High inter-session reliability is a desirable attribute of biomechanical models and is likely to be a decision factor in the development and adoption of alternate models. Interpretation of the causes of inter-session variation warrants careful consideration. This study should assist laboratories to select time intervals for future studies, extend their ability to interpret the findings and prompt consideration of a 'no-marker replacement' condition to investigate inter-session variation, in order to establish similar threshold values of intrinsic variation related to the model, selected time intervals and participant group. Additional studies are further required in clinical populations.

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Conflict of Interest Statement: The authors declare no conflict of interest

Table 2. Inter-trial kinematic variation (SD) across intervals.

		Within 2 hours	Within a day	Across a day	Across a week
Pelvic Tilt	Inter-trial SD	0.71	0.73	0.74	0.76
Hip Flex	Inter-trial SD	1.51	1.53	1.51	1.53
Knee Flex	Inter-trial SD	2.49	2.44	2.51	2.49
Ank DF	Inter-trial SD	1.99	2.01	2.02	1.97
Pelvic Obl	Inter-trial SD	0.68	0.68	0.68	0.67
Hip Abd	Inter-trial SD	0.98	0.98	0.97	0.97
Knee V	Inter-trial SD	1.93	2.01	1.73	2.06
Pelvic Rot	Inter-trial SD	1.44	1.44	1.42	1.39
Hip Rot	Inter-trial SD	2.30	2.38	2.40	2.37
Foot Prog	Inter-trial SD	2.11	2.17	2.23	2.09

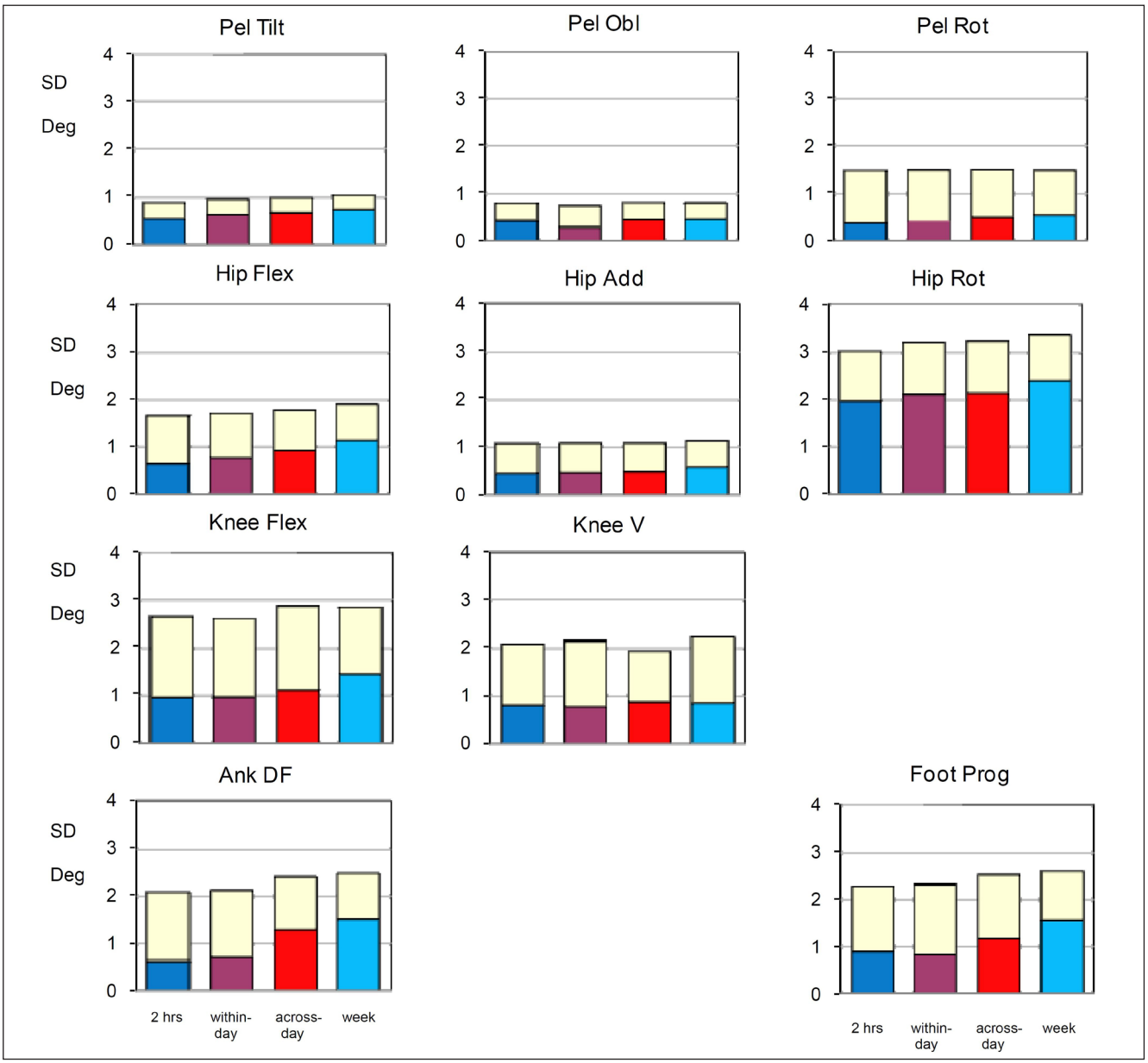

Figure 1. Inter-session kinematic variation (SD) across the different time intervals.

The total height of each column represents the total session variability, incorporating variance due to both session and trial. The height of the coloured portion indicates the magnitude of inter-session variation.

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