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Assessment of the kinematic variability among 12 motion analysis laboratories

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ABSTRACT

Variability of kinematic measurements among sites participating in a collaborative research investigation is a primary factor in determining number of subjects, level of detectable difference and statistical power of a multi-site research study. In this study, one subject was evaluated by 24 examiners at 12 motion analysis laboratories and the observed variability of nine kinematic parameters are reported. Following implementation of a standardized gait analysis protocol the same subject returned for another evaluation at each of the 12 laboratories. Additionally, system accuracy and variability of the subject within and between test days are included as factors that may affect between site variability. Marker placement among examiners is identified as the largest source of variability. A 20% decrease in variability was noted following implementation of the standardized protocol.

Three-dimensional motion analysis is commonly used to document pathologic gait for treatment planning, evaluation, and outcomes research in children and adolescents with cerebral palsy. Heterogeneity of pathology and individualized treatment of cerebral palsy have challenged the success of multi-center collaborative research. Furthermore, it can be difficult to obtain homogenous populations from a single or small number of sites to evaluate the effectiveness of treatment. These studies have been stymied by inconsistent kinematic and kinetic modeling protocols and questionable data compatibility between laboratories using differing hardware and software [1]. Recognizing these challenges, the Shriners Hospitals for Children Motion Analysis Laboratory network (SMALnet) began developing standardized data collection protocols for clinical gait analysis to enhance the capacity for collaborative studies [1]. The current study describes the variability among 12 SMALnet laboratories before and after implementing standardized data collection protocols.

In multi-center research designs, the source and magnitude of measurement error and variability are of concern, especially among examiners from different institutions [2]. Measurement errors and variability can come from three primary sources: (1) examiner, (2) measurement system, and (3) subject. Variability is defined by the sum of variances from each independent source [2,3]. Knowledge of variance is necessary for determining the number of subjects, level of detectable difference and statistical power in research studies.

Few published studies assess the variability of kinematic measures. Variability of a normal adult population within and between sessions with one examiner has been described by Kadaba et al. [4]. They found within-session variability to be low; one representative trial can generally be used for clinical decision making. In contrast, between-session variability was found to be much higher than within-session variability because of the high potential for marker placement differences. This makes reliable comparisons between sessions more challenging, even with one examiner. Such a study has not been replicated in the pediatric population.

Chambers and Goode [5] investigated the variability of kinematic measurements among five sites. More than 90% of the variability was from marker placement differences and minimal variability was attributed to system accuracy. Schwartz et al. [6] assessed within-subject, within-observer and between-observer differences within one laboratory, and revealed significant variability in transverse plane kinematics. Tirosh and Baker [7] have described a method of assessing and documenting between-examiner differences using a web-based data capture utility.

Between reviewer variability impacts the interpretation of gait analysis data. Skaggs et al. [8] assessed variability of interpretation of gait analyses from seven patients by 12 reviewers at six sites. The level of agreement for treatment recommendations among

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consistent marker placement to distinguish the variance due to the subject between days from the variance due to the examiner between days. It is possible that there were still some minor differences in alignment between days. The between-session variance was of the same magnitude as the within-session variance, suggesting that most of this variance was due to slight differences in the way the subject walked rather than to marker placement differences.

The motion capture systems themselves have some variability associated with determining marker locations. Based on these results, a properly configured and calibrated system contributes a negligible amount to the overall variability. It was expected and confirmed that the two commercial systems produce accurate and reliable 3D marker locations.

One source of variability not accounted for in this study design is that the subject could have walked differently at each site. This study took place over a several month interval at 12 sites across the United States. The effects of travel and time on the variability of kinematics were not controlled. Additionally, velocity has been shown to have an effect on gait kinematics [22,24]. The subject walked at a self-selected velocity and cadence, but did not walk with the same velocity at all sites. One alternative would have been to control cadence using a metronome as a means of controlling speed. It was felt that this would have created a less natural gait pattern that may have increased the between site variability.

Following development and implementation of a standardized gait analysis protocol, the study was repeated. Results were promising and showed an average 20% decrease in the standard deviation of 7 of 9 kinematic measures and an average 29% decrease in the maximum difference between examiners of 8 of 9 kinematic measures. Knee flexion and ankle dorsiflexion showed the greatest changes. This may be attributable to a focus in the training materials on identification of the knee flexion extension axis and reliable placement of the later femoral epicondyle marker. Foot progression angle showed a 15% decrease in standard deviation and a 31% decrease in range, which may be attributable to a focus on standardized identification of the long axis of the foot. In general, the results are promising and suggest that specific attention to marker alignment protocols may help to reduce the between examiner differences in kinematic measurement.

Care should be taken when generalizing the findings of this study to subjects with pathological gait. It is likely that differences will exist in the relative contributions of the sources of measurement error in subjects who have an abnormal gait pattern. For subjects with skeletal alignment abnormalities, marker placement may be more challenging and result in greater between examiner variability. Differences may also exist in the subject's variability in gait kinematics within and between sessions as a result of fatigue or underlying musculoskeletal or neurologic conditions.

The findings of this study point to the need for quality assurance measures and research that combine data collected from different motion analysis laboratories. The results suggest that laboratories should employ methods to reduce the variability in marker placement by examiners when involved in collaborative studies. Examiner training, the development of standardized protocols, and written descriptions of marker placement methodology may reduce examiner error. Modeling options that are not dependent on marker placement for calculating joint centers may be less variable. Longitudinal studies using different examiners, even within one site, should acknowledge measurement error as a potential contributor to observed differences. This has been recognized and promoted by Schwartz et al. [6], who have minimized between-session variability within one laboratory through improved quality assurance and training. Additionally, Tirosh and Baker [7] have recently described one method for quantifying and documenting between examiner variability.

This report documents sources and magnitudes of variability among 12 motion analysis laboratories. Marker placement differences between examiners are shown to be the most likely source of between site variability. Caution should be used when combining data from multiple sites without a standardized protocol and training program in place. Current efforts should be aimed at developing training programs to promote a uniform method of performing gait assessments to reduce measurement error between examiners.

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Conflict of interest

The authors had no conflict of interest when performing the study or when preparing the manuscript.

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