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Review

The reliability of three-dimensional kinematic gait measurements: A systematic review

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ABSTRACT

Background/Aim: Three-dimensional kinematic measures of gait are routinely used in clinical gait analysis and provide a key outcome measure for gait research and clinical practice. This systematic review identifies and evaluates current evidence for the inter-session and inter-assessor reliability of three-dimensional kinematic gait analysis (3DGA) data.
Method: A targeted search strategy identified reports that fulfilled the search criteria. The quality of full-text reports were tabulated and evaluated for quality using a customised critical appraisal tool.
Results: Fifteen full manuscripts and eight abstracts were included. Studies addressed both within-assessor and between-assessor reliability, with most examining healthy adults. Four full-text reports evaluated reliability in people with gait pathologies. The highest reliability indices occurred in the hip and knee in the sagittal plane, with lowest errors in pelvic rotation and obliquity and hip abduction. Lowest reliability and highest error frequently occurred in the hip and knee transverse plane. Methodological quality varied, with key limitations in sample descriptions and strategies for statistical analysis. Reported reliability indices and error magnitudes varied across gait variables and studies. Most studies providing estimates of data error reported values (S.D. or S.E.) of less than 5°, with the exception of hip and knee rotation.
Conclusion: This review provides evidence that clinically acceptable errors are possible in gait analysis. Variability between studies, however, suggests that they are not always achieved.

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Table 4
Factors to consider when planning or reporting a 3DGA gait reliability study.

	Descriptor
Methods	
Participants (gait)	Eligibility criteria. Recruitment strategy.
Participants (assessors)	Eligibility criteria. Recruitment strategy.
Protocol and model	Description of setting, measurement protocol, data capture systems and biomechanical models (in sufficient detail to allow study to be repeated).
Study design	Single or multiple assessors and/or labs. Number and timing of sessions and trials within session. Standardisation of assessment intervals. Variables to be investigated.
Steps to reduce bias	Has blinding of assessors occurred if appropriate?
Sample size	How has sample size been determined?
Statistical methods	Description of statistical measurements. Do these provide outcomes with the same units as the measured variables to ensure clinical applicability of results?
Results	
Participants (gait)	Description of participant characteristics.
Participants (assessors)	Description of participant characteristics with specific emphasis on professional background and experience.
Data	Report of basic temporal data parameters along with more complex gait data. Consider reporting estimates of variance of various sources: i.e. inter-trial, within-assessor, between-assessor etc

ences (MCID) [65]. Further evidence may also be sought for the responsiveness of 3DGA measures. Whether the error magnitudes are sufficiently low will be relative to the magnitude of expected intervention effect size and specific population context. Further studies are necessary in typical clinical populations to provide high quality evidence indicating whether 3DGA measures are sufficiently reliable to detect clinically important change.

5. Considerations and recommendations for future research

A number of limitations should be considered when interpreting the findings of this review. All papers were retained for inclusion regardless of study quality, in order to provide a comprehensive overview of available data. Statistical synthesis of the data was not performed. The findings of this review are limited to the published papers identified by the search strategies. Potential publication bias was not assessed and may have resulted in an over-estimation of reliability. Study quality was only reviewed by the criterion tool developed for the study purpose.

Future studies of the reliability of 3DGA require careful consideration of optimal design to enhance the generalisability of the findings. If the intention is to apply the reliability estimates to clinical populations, then careful attention is necessary to recruit and describe samples which are representative of the clinical populations of interest. Assessor recruitment and characterization warrants comparable attention. Protocols should carefully consider what standardised measurement interval is most appropriate and minimise predictable sources of assessor bias. Appropriate statistical strategies should include reliability estimates in units of degrees to enhance interpretation. Future studies should also consider evaluation of the reliability of kinetics and consider study designs that allow evaluation of the responsiveness of 3DGA. Table 4 proposes a list of factors that should be considered when designing or reporting a study of the reliability of 3DGA.

As an alternative to research with clinical participants, small studies using low numbers of healthy participants may also be appropriate, to more easily enable between-laboratory comparisons of specific techniques or biomechanical models. Further refinement and adoption of a 'standard test protocol' using methods such as those outlined by Schwartz et al. [7] may be useful. Such a protocol could specify an agreed number of trials and sessions, incorporate methods to minimise assessor bias, and adopt a specified time interval such as 1 week. This may provide a useful and more feasible approach to investigating model or technique-specific questions, prior to definitive studies in clinical populations when necessary.

This review concludes that although most errors in gait analysis are probably acceptable, they are generally not small enough to be ignored during clinical data interpretation. A goal of any clinical measurement technology must be to provide measurements that are free from any measurement error that might affect interpretation. There is thus still a need for modifying measurement techniques to reduce levels of error. Many current techniques rely heavily on the skill of assessors in accurately placing markers, and inaccurate marker placement is almost certainly the principal source of error. New techniques are now emerging based on functional calibration techniques which are, in principle, less dependent on the accuracy of marker placement (for example, see [66,67]). It is hoped that these may further reduce measurement error in clinical gait analysis. The definition of what measurement error is acceptable is, of course, dependent on the particular clinical application.

This review provides evidence that clinically acceptable errors are possible in gait analysis. Variability between studies, however, suggests that they are not always achieved and that particular care is required to achieve acceptable results.

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Conflict of interest

Author RB has received research support funding from VICON. The other authors state there were no conflicts of interest.

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