

Toe-walking quantitative assessment in individuals with autism and intellectual disabilities: comparison between human visual extraction and automated markerless gait analysis.

Background and aims

Toe-walking (TW) occurs in 20–30% of individuals with Autism Spectrum Disorder (ASD)¹. It can resolve spontaneously over time or persist, potentially leading to physical complications. Accurate TW quantification tools are essential for tracking its evolution and supporting intervention planning.

While optoelectronic and wearable motion capture are regarded as the gold standard for gait analysis, they are often not tolerated by individuals with ASD and intellectual disability. A video-based coding protocol² has been recently proposed to quantify TW in ecological settings; however, it requires manual review by trained therapists, making it time-consuming. An automated markerless gait analysis system (MGAS) approach could overcome these limitations.

This study aims to implement an MGAS approach to quantify TW and validate it by comparing the results with those obtained using the reference video-recording approach.

Methods

We conducted a preliminary study involving 13 individuals diagnosed with ASD (DSM-5 criteria), confirmed via the Childhood Autism Rating Scale (CARS-2). Intellectual disability was assessed through the Vineland-2.

TW was measured using a modified, validated protocol² based on standardised video. Participants carried an object (e.g., puzzle pieces) from a therapist to a table 3 meters away, repeating this 10 times barefoot (wearing socks). The task was performed on three separate days, totalling 39 trials.

Observing the video, a trained therapist calculated the percentage of toe steps among the total number of steps performed per trial. In parallel, videos were analysed using OpenPose³. Kinematic data were processed using a Bayesian machine learning algorithm to automatically detect total steps and toe-step percentages.

The agreement between MGAS and therapist evaluations was assessed using the Intraclass Correlation Coefficient (ICC), Bland–Altman plots, and Root Mean Square Error (RMSE).

Results

Participants (mean age: 8.75 ± 1.92 years; 9/13 males) had mean scores of 52.46 (± 6.73) on CARS-2 and 27.23 (± 12.21) on Vineland-2. Five participants exhibited TW.

The ICC demonstrated excellent reliability⁴ for total steps ($\rho = 0.993$, 95% CI: 0.987–0.996) and toe-step percentage ($\rho = 0.975$, 95% CI: 0.951–0.987). Bland–Altman plots showed minimal bias (Figure 1). RMSE was 2.24 steps for total steps and 10.25% for toe-step percentage.

Conclusion

The MGAS-based approach demonstrated high reliability and agreement with the therapist-based video coding for TW quantification in individuals with Autism Spectrum Disorder. These results support its potential as an automated, scalable alternative. Further studies on larger cohorts are required to confirm these findings.

REFERENCES

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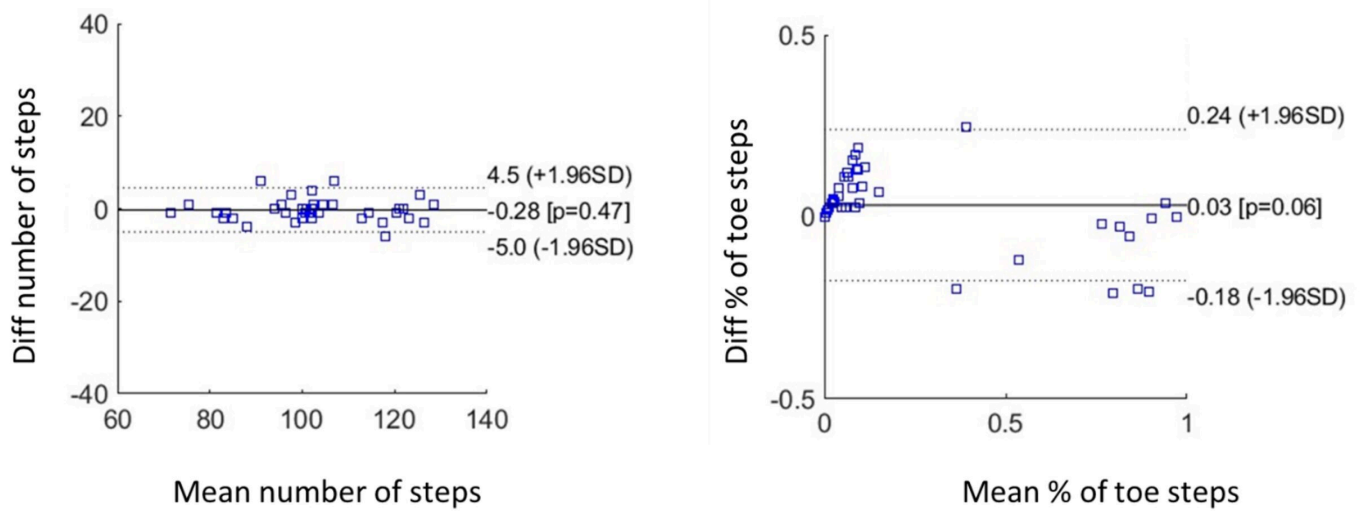


Figure 1: Distribution of the total number of steps and toe steps percentage computed for the operator and from the MGAS and Bland–Altman plots. The thin lines represent the lower and upper limits of agreement (1.96 standard deviation), and the bold line is the zero.