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DYNAMIC GAIT STABILITY IN CEREBELLAR PATIENTS

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SUMMARY

The current study aimed to evaluate dynamic gait stability in cerebellar patients. Both cerebellar patients and healthy controls walked on an instrumented treadmill at 1.0 m/s for three minutes. We calculated the short-term maximum Lyapunov exponent from the medio-lateral displacement of a marker cluster placed at the sacrum. As such, we were able to show reduced dynamic gait stability in cerebellar patients, while classic measures as step width, stride time variability and the margin of stability were similar between patients and controls. It is concluded that the short-term maximum Lyapunov exponent constitutes a valuable sensitive measure to evaluate stability in case of mild instability.

INTRODUCTION

Cerebellar damage in humans has often been associated with balance problems [1,2]. Such associations are frequently based on observations of increased medio-lateral sway, increased step width or increased variability in temporal gait parameters [1-4]. However, increases in those measures do not necessarily imply that stability of gait is decreased [5].

The current study aims to evaluate the dynamic gait stability in cerebellar patients by calculating the short-term maximum Lyapunov exponent (λ_s) from the medio-lateral displacement of the pelvis.

We hypothesize that dynamic gait stability in cerebellar patients is lower than in healthy controls. Furthermore, the results will be compared with classic measures, such as gait speed, step width, stride time variability and the margin of stability [6].

METHODS

Thirteen cerebellar patients (age: 24.3 ± 6.8 ; mean \pm SD) and nine healthy participants (23.3 ± 5.0) participated in this study. All patients displayed chronic focal lesions after cerebellar tumor resection. Severity of ataxia was rated using the International Cooperative Ataxia Rating Scale (ICARS) [7]. All participants gave written informed consent, as approved by the local ethics committee and in accordance with the Declaration of Helsinki.

Participants performed three trials of overground walking at self-selected speed, followed by three minutes of treadmill walking at 1.0 m/s. We recorded 3D position of a cluster of three retroreflective markers placed at the sacrum of the participant at 100 samples/s (Vicon Nexus, Oxford Metrics, Oxford, UK). During treadmill walking 3D ground reaction forces were collected at 1000 samples/s (instrumented

treadmill, custom built by Forcelink, Culemborg, The Netherlands).

Overground walking speed was calculated as the mean forward velocity of the marker cluster at the pelvis during the three overground walking trials.

For the treadmill walking trials, instants of heel strike and toe-off were calculated, based on the center of pressure [8]. For each participant, we included 150 strides for all gait analyses. We calculated the short-term maximum Lyapunov exponent from the medio-lateral displacement of the marker cluster at the pelvis, following Bruijn's protocol [9].

In short, the Euclidean distance between each data point in state space and its nearest neighbor was tracked over time. A divergence curve was constructed by taking the log of the mean of all these time-distance curves. The short-term maximum Lyapunov exponent is the slope of this divergence curve over 0-0.5 strides.

Negative values of λ_s indicate that the system (in this case the medio-lateral displacement of pelvis) is locally stable, while positive values indicate local instability and higher values for λ_s imply less local stability [9,10].

Additionally, we calculated step width and the medio-lateral base of support and we estimated the center of mass, from the center of pressure. We calculated the "extrapolated center of mass" (XCoM) from the estimated center of mass and its velocity and we assessed the safety margin between the XCoM and the base of support [6]. This 'margin of stability' quantifies how close an inverted pendulum model of the participant would be from falling. A greater margin is related to more stable gait, but could also result from a step-widening strategy during unstable locomotion [11,12].

Finally, we calculated the coefficient of variation values for stride time similar to Schniepp et al [4].

Student's t-test was used to compare all gait (stability) measures between groups. We applied linear regression analyses to evaluate correlation between different measures within the patient group. Each of the 5 gait measures was tested for correlation with ICARS score and with the other 4 gait measures; appropriate Bonferroni correction was applied to the level of significance.

RESULTS AND DISCUSSION

ICARS scores in the cerebellar patient group ranged from 0 to 19 (7.4 ± 5.9). An overview of the different gait measures for both groups is presented in Table 1. Cerebellar patients

displayed a lower overground walking speed as compared to healthy controls. From the measures, classically related to gait stability, only λ_S values differed significantly between groups. Additionally, no significant correlation was observed between any of the tested measures within the patient group, except for a correlation between step width and margin of stability ($p < 0.0001$).

These results indicate that classic measures as step width, stride time variability and the margin of stability are not necessarily correlated with dynamic gait stability. Furthermore, in a patient group with relative mild deficits (ICARS ≈ 7) these gait measures are similar to those in healthy controls. Alternatively, the short-term maximum Lyapunov exponent of a marker cluster at the pelvis was higher for the patient group, indicating dynamically less stable gait. In addition it was found that this measure does not overlap with other stability measures, indicating that it addresses a specific aspect of stability. In contrast, some of the other measures showed overlap with each other. For example, margin of stability was observed to be correlated to the step width, which is related to the fact that the base of support is a base for the calculation of both the step width and the margin of stability.

CONCLUSIONS

We used a simple 3 minute protocol of walking at 1.0 m/s on an instrumented treadmill with a marker cluster at the pelvis. By calculating the short-term maximum Lyapunov exponent from the medio-lateral displacement of the marker cluster over 150 strides, we were able to show reduced

dynamic stability of gait in cerebellar patients, while simple measures as step width and stride time variability were similar between patients and controls. It is concluded that the short-term maximum Lyapunov exponent constitutes a valuable sensitive measure to evaluate stability in case of mild instability.

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Table 1: Gait measures (mean \pm SD) for cerebellar patients and healthy controls.

	Cerebellar patients	Healthy controls	p-values
Overground walking speed (m/s)	1.11 \pm 0.14	1.28 \pm 0.10	0.01*
λ_S	1.75 \pm 0.15	1.62 \pm 0.11	0.04*
Step width (m)	0.24 \pm 0.04	0.22 \pm 0.03	0.24
Stride time variability (%)	3.13 \pm 0.81	3.01 \pm 0.72	0.74
Margin of stability (mm)	84 \pm 13	81 \pm 14	0.64

* Significantly different between groups