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► To cite this version:

Nicolas Forestier, Brice Picot, Jeanne Dury, Guillaume Néron, Pierre Samozino, et al.. Validity and reliability of video analysis to evaluate ankle proprioceptive reintegration during postural control. *Gait & Posture*, 2022, 91, pp.155-160. 10.1016/j.gaitpost.2021.10.022 . hal-03556856

HAL Id: hal-03556856

<https://hal.science/hal-03556856>

Submitted on 5 Jan 2024

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Validity and reliability of video analysis for ankle proprioceptive reintegration during postural control.

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Declarations of interest: none

Abstract:

Background: The ability to dynamically reintegrate proprioceptive signals after they have been perturbed is impaired in certain pathologies. Evaluation of proprioceptive reintegration is useful for clinical practice but currently requires expensive laboratory tools. We developed a simple method, accessible to clinicians.

Research question: Is two-dimensional (2D) video analysis of earlobe displacement a valid and reliable tool for the evaluation of ankle proprioceptive reintegration following muscle vibration?

Methods: Thirty-eight healthy individuals underwent vibration of the triceps surae while standing on a force plate (FP). Anterior (sagittal plane) earlobe displacement ('overshoot') was recorded at vibration cessation using 2D video analysis and rated by 3 blind examiners. Correlation analysis was performed between earlobe and center of pressure displacement (*d*CoP, recorded with the FP) to determine validity. Intra and interrater reliability were determined by calculation of the intraclass correlation coefficient (ICC), change in the mean (CiM), standard error of measurement (SEM) and the minimal detectable change (MDC).

Results and significance: Strong positive correlations ($r=0.82-0.94$, $p<0.001$) were found between video and FP data. Intra- and interrater reliability were excellent (ICC from 0.99 to 1.00 and from 0.90 to 0.97 respectively). For intrarater analysis, the CiM was 0.01cm, SEM were 0.27cm (95% CI: 0.23 to 0.33) and 3.43% (95% CI: 2.92 to 4.20) and the MDC was 0.74cm. For interrater reliability, the CiM ranged from -0.81 to 0.55cm, the SEM from 0.61 to 1.12cm and the MDC from 1.69 to 3.10cm. 2D video analysis of anterior (sagittal) earlobe displacement is therefore a valid and reliable method to assess postural recovery following muscle vibration. This simple method could be used by clinicians to evaluate the ability of the central nervous system to reintegrate proprioceptive signals from the ankle. Further studies are needed to assess its validity in individuals with proprioceptive impairment.

Keywords: video analysis, reliability, sensory reweighting, ankle proprioception, vibration, posture

Introduction

Postural control requires the integration of sensory information from the visual, vestibular and proprioceptive systems by the central nervous system (CNS) [1]. Depending on the reliability of the different signals in the environmental context, the CNS shifts reliance from one type of afferent signal to another, this is termed sensory reweighting [2,3].

Proprioceptive information from the ankle plays a major role in postural control and has been related to performance and injuries in sport [4]. A variety of methods exist to evaluate ankle afferent signals [5], however, they cannot all be used during functional tasks. Muscle vibration is a simple and reliable tool to assess proprioceptive integration during balance tasks [6,7]. Vibration stimulates primary (Ia) afferents fibers in muscle spindles, considered as the most important kinesthetic sensors [8,9]. Stimulation of a postural muscle creates a perception of muscle lengthening that generates a corrective response to maintain perceived verticality [7,10]. For example, vibration of the triceps surae (TS) at around 80Hz generates a postural response of the subject which shifts the center of pressure posteriorly [11].

Proprioceptive reintegration is defined as the ability of the CNS to reuse the signal from the vibrated area once the vibration has ceased and the signals have become reliable once more [12–14]. Immediately after vibration cessation, the CNS reweights sensory afferents to reintegrate information from the previously perturbed system [15–17]. It has been shown that the ability to reintegrate ankle proprioceptive information after vibration cessation is impaired in various conditions such as low back pain [18], in adolescents with idiopathic scoliosis [19] and in elderly and faller populations [12,16]. Conversely, expert gymnasts have a greater ability to reintegrate ankle signals following vibration cessation compared to non-gymnasts [13]. It therefore seems relevant to assess proprioceptive reintegration in clinical practice to identify impairments or evaluate the effectiveness of rehabilitation protocols in individuals with disorders that can lead to impaired proprioception. However, such evaluations currently require the use of force plates (FP) coupled with advanced analysis methods which are not always available in clinical practice and are mainly reserved for experimental research.

We therefore set out to develop a simple, but accurate, method that could be used to assess sensory reweighting processes in the clinical setting. Since ankle vibration mainly induces postural responses

in the sagittal plane [20] we hypothesized that recording body sway in this plane could provide a measure of sensory reweighting following ankle vibration. At the instant of cessation of vibration of the triceps surae muscle, an abrupt forward motion of the subject occurs, termed “overshoot” [7] (see supplementary material). The magnitude of the overshoot, which varies across healthy individuals, reflects sensory reweighting processes and is considered as the most reliable variable to assess the reintegration of proprioceptive information from the ankle [7]. We postulated that this overshoot could be evaluated simply by measuring the displacement of an anatomical landmark using video analysis [21]. For this purpose, we sought a landmark that was distant from the ankle to ensure sufficient motion for manual video detection (i.e. the body functions as an inverted pendulum at the overshoot). We chose the earlobe since it is both distant from the ankle and easy to identify [22].

Video recordings combined with freely available software (Motion Analysis tools, Kinovea, Mokka, etc.) can be used to generate two-dimensional (2D) kinematic data [23]. Furthermore, video analysis is an easy-to-use portable tool [21] that has been widely used in sport sciences [24–26] and in the clinical field [27,28] and could be used in routine assessments. However, to our knowledge, due to the static nature of quiet standing, it has never been used to evaluate postural or proprioceptive processes. Although studies have found this method to be reliable and accurate in various contexts [21,23] the reliability and validity of video analysis has not been evaluated in the context of sensory reweighting.

The primary aim of this study was to assess the validity of earlobe displacement measured from 2D video analysis using Centre of Pressure (CoP) displacement as the reference. We hypothesized that earlobe displacement would be correlated with CoP displacement at vibration cessation. The secondary aim was to evaluate the intra- and interrater reliability of the measurement of earlobe displacement using 2D video analysis.

Methods

Participants:

We included 38 young healthy individuals (20 males and 18 females, mean age 15.0 ± 0.1 years, height 178 ± 8.5 cm, mass 66.9 ± 11 kg), recruited from the sports science department. Exclusion criteria were

known neurological disorders, vestibular impairment, and musculoskeletal injuries within the previous 3 months (ankle sprains, anterior cruciate ligament ruptures etc.). A clinical examination was performed by a physiotherapist to ensure that all individuals were eligible for participation. All participants (legal guardians for participants <18 years) provided written informed consent and the protocol was approved by our regional Ethical Committee.

Procedure:

Balance control was assessed using data from a force plate (FP) (AMTI, model BMS464508, Watertown, MA). Participants were asked to stand barefoot in bipedal stance on the FP with their arms relaxed by their sides and head in a neutral orientation. Foot position was standardized by marks on the floor: the heels were 10 cm apart, but the forefoot position was non-standardized. Opaque goggles were used to block vision.

Vibration

Two muscle vibrators (VB115, Techno Concept, Mane, France) were placed bilaterally on the Achilles tendons. The triceps sural muscles were stimulated at 80Hz with an amplitude of 0.5mm [6,9,29]. The vibration was applied after 10 seconds (PRE) for a duration of 20 seconds (VIB). The vibrators were then switched off simultaneously and automatically and participants were instructed to stand still for the next 20 seconds (POST) [7]. Two LEDs positioned on the wall in front of the camera were synchronized with the vibrators to indicate the exact moment when the vibration stopped for the purpose of the analysis.

Video recording

A visual marker was positioned on the participant's earlobe (marker 1) to facilitate automatic tracking by the video software. A 5 cm scale was placed at the participant's feet in the sagittal plane and used to calibrate the video analysis (Figure 1B). An iPad Pro (13.2.3, 1080pixels, Apple) was used for the recording and placed on a 1m high tripod located at 2.80m to the FP with the optical axis

perpendicular to the plane of movement (i.e. sagittal) and covering the entire field of the subject. A mark was placed on the floor to standardize the tripod position.

Data analysis:

Force plate data were sampled at 1000Hz with DColl software (GRAME, Laval University, Quebec, Canada). Signals were filtered using a fourth order, low-pass Butterworth filter with a cut-off frequency of 10Hz. Centre of pressure displacements ($dCoP$) in the sagittal plane (anterior–posterior direction) were calculated using forces and moments from the FP with a custom software developed in Matlab (The MathWorks, GRAME, Laval University, Quebec, Canada) using the equation: $COP = M_x / F_z$.

The study by Kiers et al. [7] showed that the most reliable variable for the evaluation of proprioceptive reintegration is the anterior “overshoot”, expressed as the distance (in cm) between the maximum anterior CoP position (“peak”) that occurs just after the cessation of vibration and the mean CoP position during the last 5s of vibration (Figure 1a). Rater 1 (R_1) therefore calculated this parameter which was then used as the gold standard for comparison with the video analysis.

The video recording was set to capture 60 frames per second, corresponding to 17ms between frames. Video analysis was performed with Kinovea (0.8.15, available for download at: <http://www.kinovea.org>). Each recording was analyzed by three blinded raters (R_1 , R_2 , R_3) independently and on separate computers. R_1 performed a second analysis of the same 38 videos 7 days later (R_1S_1 and R_1S_2). All raters were experienced and familiar with video analysis. The raters were instructed to evaluate the “visual overshoot”: the total distance covered by the earlobe between the last frame of the vibration phase (i.e. the first with the LEDs switched on), and the maximal anterior position reached during the next 5 seconds (Figure 1b). To do this, they first performed a calibration using the 5cm scale, which was equal to 26pxl (Figure 1b). Then they manually selected the first frame when the LEDs switched on (i.e. the beginning of vibration cessation) and marked the earlobe of the subject (marker 1) using the mouse, then they selected the last frame of the overshoot (the most anterior position of the subject during the 5s post vibration). The software automatically

tracked and computed the total distance covered by marker 1 (Figure 1b). To improve the accuracy of marker placement, the selection was performed with a 350% zoom.

Please insert figure 1 here

Statistical analysis

Statistical analysis was performed using SPSS software (SPSS Inc, Chicago, IL). All data were checked for normality using a Shapiro Wilk test.

Validity

A Pearson's correlation analysis was performed between $dCoP$ and the maximal forward displacement of the earlobe measured by R_1S_1 . The degree of correlation (r) was defined according to the following guidelines: ≤ 0.20 = very weak, $>0.20 - 0.40$ = weak, $>0.40 - 0.70$ = moderate, $>0.70 - 0.90$ = strong and >0.90 = very strong [30]. The level of significance was set at 0.05.

Reliability

Relative intra- and interrater reliability were calculated using Intraclass Correlation Coefficients ($ICC_{2,1}$) and interpreted as "poor" for values below 0.5, "moderate" between 0.5 and 0.75, "good" between 0.75 and 0.9 and "excellent" above 0.90 [31,32]. Absolute reliability was quantified by the Change in the Mean and the Standard Error of Measurement in raw units (SEM_{cm}) and percentages (SEM%), and interpreted using the Minimal Detectable Change (MDC_{cm} and MDC%) with 95% confidence intervals (CI) using the equation [33]: $MDC = 1.96 \times \sqrt{2} \times SEM$.

Results

Mean (\pm standard deviation) CoP overshoot value was 6.52 ± 2.45 cm and mean earlobe overshoot values were 7.86 ± 3.42 cm (R_1S_1), 7.87 ± 3.43 cm (R_1S_2), 8.67 ± 3.67 cm (R_2) and 8.12 ± 3.52 cm (R_3).

Validity

Correlation between anterior earlobe displacement and $dCoP$ was strong to very strong, significant and positive (R_1S_1 vs FP; $r= 0.89$, [95% CI: 0.82 to 0.94], $p<.001$; R_1S_2 vs FP; $r =0.84$, [95% CI: 0.73 to 0.90], $p<.001$; R_2 vs FP, $r= 0.91$, [95% CI:0.84 to 0.95], $p<.001$; R_3 vs FP, $r =0.84$, [95% CI:0.73 to 0.90], $p<.001$) (Figure 2).

Please insert Figure 2 here

Reliability

- Intrarater reliability:

Intrarater reliability was excellent ($ICC_{2,1}=0.99$, 95% CI: 0.99 to 1.00). The change in the mean was 0.01cm. The SEM values were 0.27cm (95% CI: 0.23 to 0.33), and 3.43% (95% CI: 2.92 to 4.20%). The MDC was 0.74cm (Table 1).

- Interrater reliability:

Interrater reliability was excellent ($ICC_{2,1}=0.94$, 95% CI:0.90 to 0.97). The change in the mean ranged from -0.81 to -0.55cm. Interrater SEM was 0.88 cm, with a range of 0.61 to 1.12cm. MDC ranged from 1.69 to 3.10cm (Table 1).

Please insert Table 1 here

Discussion

The purpose of this study was to evaluate the validity and reliability of earlobe displacement obtained from 2D video analysis to measure proprioceptive reintegration of the ankle at vibration cessation in quiet standing. Comparison of sagittal plane video recordings with data from a force plate showed a very strong positive correlation between CoP and earlobe displacement, demonstrating excellent validity and consistency of the anterior shift of the head (i.e. body sway) as a measure of the ability to reintegrate proprioceptive signals after vibration cessation. Moreover, the freely available software for the 2D video analysis tracked earlobe displacement with sufficient accuracy.

Although strong (r ranging from=0.84 to 0.91), the correlation between earlobe and CoP displacement was not perfect. This can be partially explained by the fact that CoP displacement is not completely

reliable [7] although it is considered as the gold standard for the measurement of proprioceptive reintegration. The process of analysis of CoP displacement (sampling and cut-off frequency) [34] can thus lead to variability in the calculation of the overshoot.

Both intrarater and interrater reliability were excellent. Intrarater reliability was further confirmed by the very low SEM_{cm} and SEM% values. The effect size of the MDC value, when standardized to interindividual variability, was trivial to small, which means that very small differences in proprioceptive reintegration could be detected in our sample. It is therefore likely that the method would also be sensitive enough to detect change in pathological populations. Moreover, the freely available software for the 2D video analysis tracked earlobe displacement with sufficient accuracy.

Impaired ankle proprioceptive reintegration has been found in patients with non-specific low back pain [18] and in adolescents with idiopathic scoliosis [19]. A reduced ability to reintegrate ankle signals in elderly individuals has been shown to be predictive of falls [16]. Furthermore, an exacerbated ankle-driven proprioceptive control strategy is a risk factor for low back pain among young healthy individuals [11]. The evaluation of proprioceptive reintegration would therefore be useful for clinicians before beginning sensory reintegration training in patients with musculoskeletal disorders and to evaluate outcomes [18]. Further studies are needed to assess the ability of video analysis to determine proprioceptive postural control strategies in clinical practice [35].

Several aspects of the method presented here could be improved. Intra- and interrater variability was mostly due to differences in the selection of the last frame for the anterior displacement (i.e. the most anterior position of the earlobe). To reduce this variability (and increase reliability), we suggest that vertical markers could be positioned behind the subject to help evaluators to identify the last frame of the “overshoot” period. Closer-up filming of the subject would improve the resolution of the video images and thus both the accuracy and reliability of frame selection. However, if only the head is filmed, an appropriate position for the calibrating scale must be found. This could be considered in the future development of this tool. We used Kinovea software for the video analysis because it is freely available and therefore could be used in clinical practice. It seems reasonable to expect that other free software would provide similar results. However, the accuracy of the method could potentially be improved by more powerful software. The use of an algorithm to detect and track earlobe

displacement would further simplify this method and make it more objective. This could be considered for the future development of the tool.

This study has several limitations. Firstly, the three raters were familiar with Kinovea software and video analysis. It is possible that reliability would be lower for less experienced raters. Secondly, we included young, healthy, sporty individuals. The results cannot therefore be generalized to other populations and further studies should be carried out to evaluate the validity of this method in older adults and individuals with proprioceptive disorders.

The main strengths of this study are that it involved a large number of participants ($n > 30$) who displayed wide “overshoot” results (ranging from 1.36 to 12.48cm) and that three blind raters performed the analysis; characteristics which are essential for a good reliability study [31,32].

Conclusion

This study showed that the evaluation of proprioceptive reintegration using kinematic data from the earlobe and simple video analysis is valid. The forward displacement of the earlobe was correlated with CoP displacement following ankle tendon vibration. Furthermore, intra and interrater reliability were both excellent. This simple, low-cost method could be used in clinical practice to evaluate sensory reweighting processes. However, further studies are needed to evaluate this procedure in individuals with proprioceptive disorders.

Conflict of interest statement: None

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TABLES

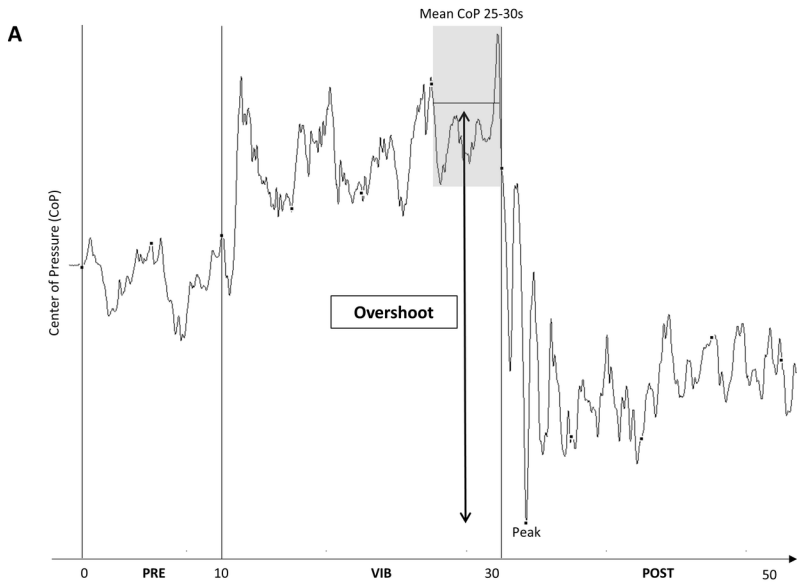
Table 1. Intra (R_1S_1 vs R_1S_2) and interrater (R_1 vs R_2 vs R_3) reliability analysis.

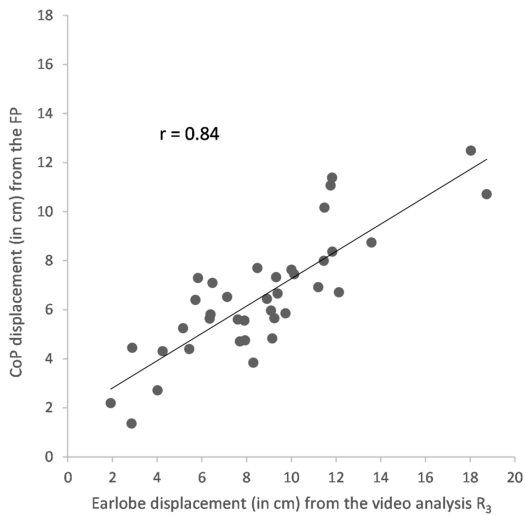
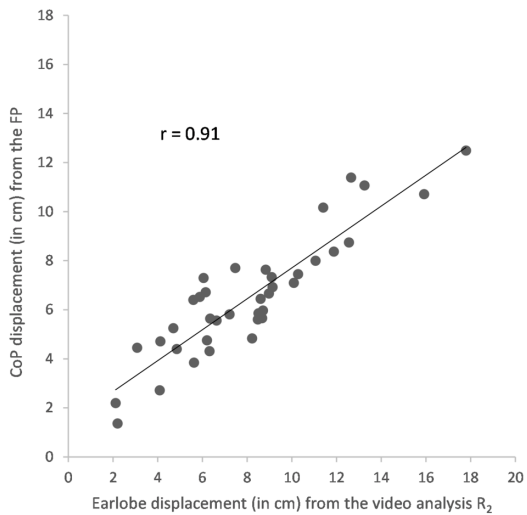
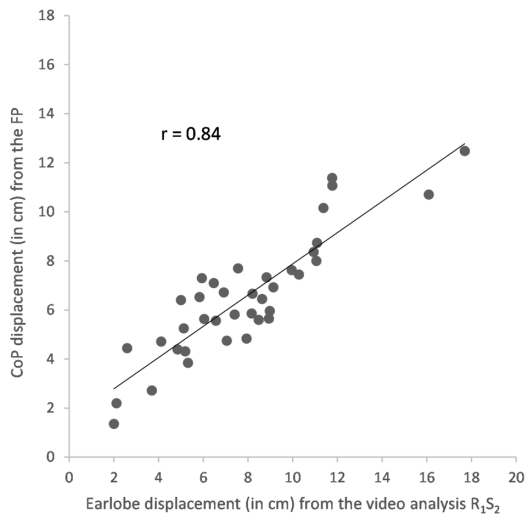
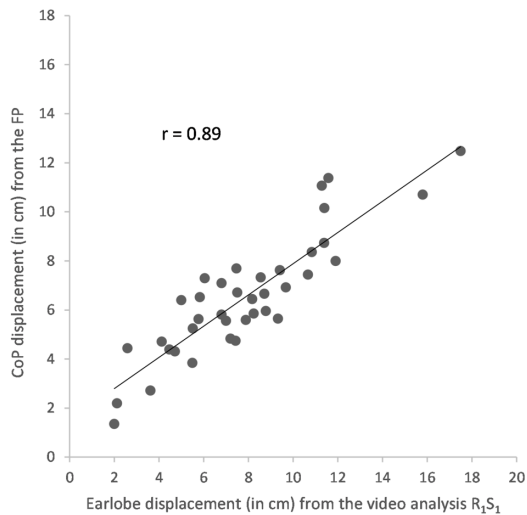
FIGURES

Figure 1. Center Of Pressure displacement (*dCoP*) calculated from force plate data in the A/P axis (A) anterior displacement of the earlobe from the 2D video recording following vibration cessation (B).

Figure 2. Correlation between earlobe displacement obtained from video analysis by R_1S_1 , R_1S_2 , R_2 and R_3 , and center of pressure displacement (*dCoP*) calculated from force plate data (FP).

Note: R_1S_1 = Rater 1 Session 1, R_1S_2 = Rater 1 Session 2, R_2 = Rater 2 and R_3 = Rater 3.





	Intra-rater reliability	Inter-rater reliability		
	Rater 1 S₁ vs Rater 1 S₂	Rater 1 vs Rater 2	Rater 2 vs Rater 3	Rater 1 vs Rater 3
ICC (CI)	0.99 (0.99 - 1.00)	0.94 (0.90 - 0.97)		
SEMcm (CI)	0.27 (0.23-0.33)	0.83 (0.7-1.02)	1.12 (0.94-1.39)	0.61 (0.52-0.76)
SEM% (CI)	3.43 (2.92 - 4.20)			
MDC (cm)	0.74	2.3	3.10	1.69
CiM (cm)	0.01	-0.81	0.55	-0.26

ICC=Intraclass correlation coefficient. SEMcm= standard error of measure in cm, SEM%= Standard error of measure in %, MDC= Minimum detectable change, CI=95% confidence interval, CiM= Change in the Mean