

## Concurrent validity of two-dimensional motion analysis using Kinovea for measuring spatiotemporal gait parameters in healthy individuals

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### KEYWORDS

Gait; Walking;  
Psychometric  
property;  
Physiotherapy;  
Rehabilitation.

### ABSTRACT

Spatiotemporal gait parameters are usually used as crucial indicators for quantifying rehabilitation effectiveness and several clinical outcomes such as gait and balance ability, and risk of falls of many individuals. Kinovea is an open software for analyzing captured images. The validity of this software has been extensively studied for joint angle measurement, but it is unclear for the measurement of spatiotemporal parameters, which limits its application. Thus, the study explored the concurrent validity and agreement of Kinovea to detect spatiotemporal gait parameters as compared to a criterion measure. Fifty-one healthy participants (age range from 18 to 59 years) were instructed to walk along a 10-m walkway for three trials. Stride length, cadence, gait symmetry and walking speed were assessed using Kinovea and APDM® Mobility Lab (APDM) system. Pearson's correlation coefficients, concordance correlation coefficients (CCC) and Bland-Altman plot were utilized to explore the concurrent validity and agreement of the Kinovea findings and standard measures. Excellent validity and agreement were found for Kinovea in calculating spatiotemporal parameters ( $r > 0.95$ : CCC  $> 0.85$ ,  $p$ -value  $< 0.001$ ). Moreover, the Bland-Altman plot data were uniformly-scattered around the horizontal axis and under the limit of agreement. The findings conclusively confirm the validity of Kinovea for spatiotemporal parameters as verified using a standard measure. Thus, this software can be used as an alternative assessment for clinicians in various clinical-based and community-based settings.

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## Introduction

Spatiotemporal gait parameters, such as stride length, step symmetry and cadence, have been used for various objectives including quantifying rehabilitation effectiveness and being a representative of sensorimotor deficits, walking capability, balance ability, and falls risk<sup>(1-4)</sup>. Technically, these parameters are delivered via a valid and reliable method of three-dimensional motion analysis or inertial sensors<sup>(5,6)</sup>. However, the technique has several limitations affecting the application in clinical and community settings, such as high cost, low portability, and the skill needed to operate the systems<sup>(7-9)</sup>. On the contrary, the conventional footprint has been criticized for its invalid and unreliable for clinical and research works<sup>(10)</sup>.

Consequently, a two-dimensional (2D) motion analysis has been proposed to minimize problems of the aforementioned methods<sup>(7-9)</sup>. Among many programs of 2D analysis, the Kinovea® (Kinovea) is an open-license software that is commonly used to assess joint angle validly and reliably of several activities such as sitting, running, and jumping<sup>(11-14)</sup>. However, there are few studies supporting psychometric properties of some spatiotemporal gait measurements such as stride length and gait speed, which limit their clinical and research application for all gait variables needed as clinical outcomes<sup>(12,15)</sup>. In addition, the existing validity data regarding Kinovea involved only the young adults, whereby a recent study has suggested that gait parameters have been changed throughout lifetime periods<sup>(16,17)</sup>.

Therefore, the objective of this study is to evaluate the validity and agreement of 2D motion analysis using Kinovea software compared to a criterion measure (inertial sensor) in analyzing spatiotemporal parameters during walking at a preferred speed among healthy individuals (age ranged 18 to 59 years). The findings would further support clinical and research utility of Kinovea program for spatiotemporal gait measurements in healthy adults.

## Materials and methods

### *Study design and participants*

This study was cross-sectionally carried out between June and August 2023 in healthy adults. The eligible participants aged 18-59 years, had body mass index (BMI) between 18.5-29.9 kg•m<sup>-2</sup> and were able to understand, communicate, and follow the instructions used in the study, and possessed the ability to walk at least 10 meters without any assistance or devices<sup>(2,8)</sup>. Individuals with a condition that could affect and confound outcomes during a 10-m walk, such as acute pain or inflammation in the muscles or joints, (i.e., >5 out of 10 on a visual analogue scale), leg length discrepancy (> 3 cm) or lower extremity deformity were excluded from the study<sup>(18)</sup>.

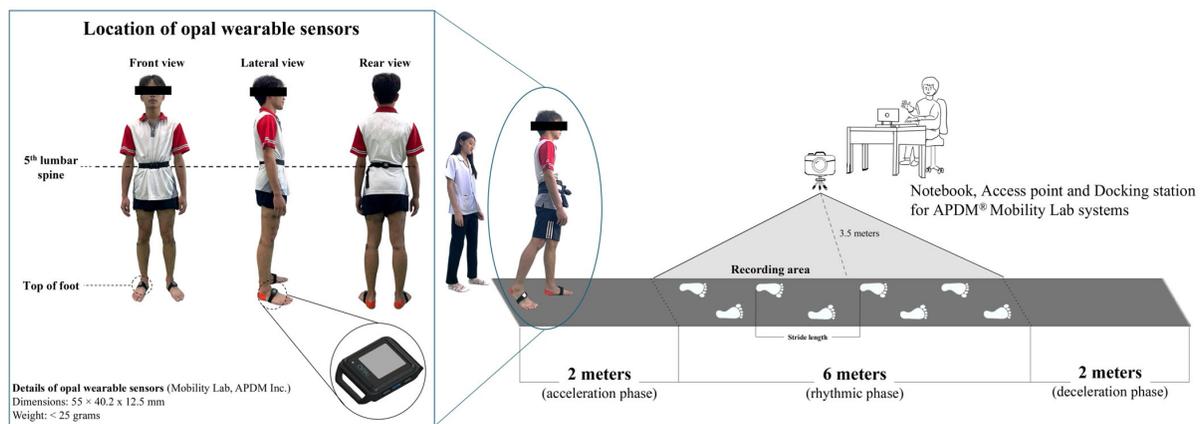
The sample size estimation for the primary objective of the study (concurrent validity) was calculated with the lowest level of correlation (r) reporting in a previous study of 0.45<sup>(19)</sup> and the  $\alpha$  of 0.05. The findings indicated that this study required at least 44 participants to obtain 90% power of test. In addition, systematic review and previous statistical studies recommend that at least 50 participants are adequate to minimize selection bias for a validity and agreement study<sup>(20,21)</sup>. Thus, this study recruited at least 50 participants and then stratified them into four age groups, including 18-29, 30-39, 40-49, and 50-59 years (at least 10 participants in each group) to ensure the generalizability of the findings in healthy individuals. Eligible participants subsequently signed an informed consent document approved by Srinakharinwirot University Ethics Committee in human research (SWUEC 019/66) before participation in the study.

### *Research protocol*

An assessor was trained by an expert (>5-year experience) for the methods of administering the APDM's Mobility Lab (APDM) and mounting the camera. In details, the camera was mounted on a stationary tripod in the middle of the walkway at approximately 3.5 meters away from and

perpendicular to the walkway to capture gait variables of participants over the middle 6-m of a 10-m walkway (at least three-consecutive stride lengths)<sup>(22)</sup> (Figure 1). Then a preliminary study was conducted in ten participants to assure smoothness of the protocol.

The eligible participants were interviewed and assessed for their demographics, i.e., age, gender, BMI, and vital signs. Three opal wearable sensors of APDM were attached at the base of the 5<sup>th</sup> lumbar spine and centered on top of the left and right feet of the participant (Figure 1)<sup>(5,23)</sup>.



**Figure 1** Testing protocol and setting of data recording.

### Testing protocol

Participants were instructed to walk barefoot along a 10-meter walkway for three trials at their preferred speed. During the test, their three-consecutive stride lengths of each lower extremity were recorded over six meters in the middle of the walkway to obtain the data over a rhythmic phase (Figure 1). Participants were fastened with a lightweight safety belt with an assessor always being or walking alongside them. The participants could take a period of rest (if needed)<sup>(18)</sup>.

After the test, the spatial data were then analyzed from 2D motion video using a method of manual digitization in Kinovea by counting the pixels between the distances from the heel of one leg to the heel of the other leg and scaling with respect to the calibration object. Then, the average step length of each lower extremity was subsequently calculated using the following formula<sup>(22)</sup>.

$$\text{Stride length} = \text{average right step length} + \text{average left step length}$$

$$\text{Percent of gait symmetry} = \left[ \frac{(\text{average data of the shorter stride length})}{(\text{average data of the longer stride length})} \right] \times 100$$

$$\text{Walking speed} = (\text{stride length} \times \text{cadence}) \times 120^{-1}$$

In addition, cadence was obtained by calculating the number of steps in a minute.

$$\text{Cadence} = \text{number of steps in one minute}$$

### **Data acquisition and processing**

#### **Instrumentations**

Criterion measures: Previous studies reported that inertial wearable sensors can be used as substitution for conventional laboratory gait analysis systems<sup>(5,23,24)</sup>. Thus, APDM's Mobility Lab™ (APDM Inc., Portland, OR, USA) was selected as the gold standard gait measurement tool in the current study<sup>(23)</sup>. Spatiotemporal gait parameters were calculated using an algorithm in a gyroscope ( $\pm 400^\circ/\text{s}$  range) and an accelerometer ( $\pm 5\text{g}$  range) with a sampling rate of 200 Hz to record angular movement and acceleration<sup>(23)</sup> (Figure 1).

2D motion analysis: A high-resolution (1,920 x 1,080 pixel of the full HD standard) Panasonic Lumix DC-G95 camera (Panasonic Corporation Co., Ltd., Osaka, Japan) was used to collect data during 10-m walkway. Prior to the test, the algorithm of Kinovea software (Kinovea 0.9.5 for Windows; available at <http://www.kinovea.org>) was calibrated using the known length object (33.5 x 45.5 x 10 cm) with an obvious marker at the corner of the box<sup>(8,22)</sup>.

#### **Statistical analysis**

Descriptive statistics were used to explain the demographics of participants as well as the findings of the study. The Kolmogorov-Smirnov test was applied to estimate the normality of the data distribution. Pearson's correlation coefficient ( $r$ ) was used to explain the levels of correlation (concurrent validity) and relative agreement between the two systems. The strength of the correlation was defined as poor ( $r = 0.30-0.49$ ), moderate ( $r = 0.50-0.69$ ), and excellent ( $r > 0.70$ )<sup>(20)</sup>. The levels of significant differences were set at  $p$ -value  $< 0.05$ <sup>(25)</sup>.

To measure agreement, Bland-Altman analysis was used to inspect the error scores between the two systems with respect to the mean scores. This method demonstrates any tendency for the variation to change with the magnitude of the measurement<sup>(26)</sup>. Moreover, the concordance

correlation coefficient (CCC) was applied to obtain an overall agreement between the two systems. The level of the CCC was determined as poor (CCC  $< 0.4$ ), moderate (CCC = 0.40-0.74), and excellent (CCC  $> 0.74$ )<sup>(27)</sup>. In addition, the percentage error was computed to express the standard deviation (SD) of the between-method difference scores (bias) as a percentage of the mean measure of the two systems using the formula<sup>(7)</sup>:

$$PE = (100 \times (2SD \text{ of bias}) / [(Mean_{Kinovea} + Mean_{APDM}) / 2])$$

### **Results**

A total of 54 individuals were screened for their eligibility according to the criteria of this study, and three individuals were excluded because of BMI exceeding normal range ( $n=2$ ), and signs of inflammation of the lower extremity ( $n=1$ ). The 51 remaining participants were enrolled and completed the study. Their average age was approximately 38 years old with a normal BMI and most of them were female. Stride length, gait symmetry, cadence, and walking speed are also summarized in table 1.

The percentage error and agreement values are provided in table 2. Stride length, gait symmetry, cadence, and gait speed possessed strongly excellent correlations and overall agreement between both systems, with low percentage errors ( $r$  and CCC values  $> 0.85$  and percentage error = 2-5%). The linearity assessment for the agreement of landmark detection with respect to distance from Kinovea software is provided in figure 3, with the points on the Bland-Altman plot being uniformly and tightly scattered around the horizontal axis (Figure 3).

The correlations between 2D motion analysis using Kinovea and APDM systems were also high for the stride length, gait symmetry, cadence, and gait speed ( $r = 0.91 - 0.99$ ,  $p$ -value  $< 0.01$ ) (Figure 2).

**Table 1** Demographic of participants

Variable	N = 51	Min/Max
Number of participants in each age group: n (%)		
- 18-29 years	14 (27.45)	-
- 30-39 years	15 (29.41)	-
- 40-49 years	11 (21.57)	-
- 50-59 years	11 (21.57)	-
Gender: Female: n (%)	33 (64.70)	-
Age <sup>a</sup> (years)	37.73 ± 11.84 (34.40-41.06)	18/59
Weight <sup>a</sup> (kg)	60.70 ± 10.19 (57.83-63.56)	43/79
Height <sup>a</sup> (cm)	160.69 ± 7.81 (158.49-162.88)	145/175
Body mass index <sup>a</sup> (kg•m <sup>-2</sup> )	23.42 ± 3.06 (22.56-24.28)	18.7/29.7
Stride length <sup>a</sup> (meter)	1.20 ± 0.11 (1.18-1.21)	0.98/1.50
Gait symmetry (%)	97.72 ± 2.28 (97.36-98.08)	90/99
Cadence <sup>a</sup> (step/minute)	119.97 ± 8.72 (118.58-121.37)	100/144
Gait speed <sup>a</sup> (meter/second)	1.21 ± 0.17 (1.18-1.23)	0.85/1.7

**Note:** <sup>a</sup>The data are presented as mean ± standard deviation (95%CI).

**Table 2** Mean difference in 2D motion analysis (Kinovea) and inertial sensors (APDM) system derived spatiotemporal gait parameters, along with 95% limits of agreement (LoA), percentage error (PE), and concordance correlation coefficients (CCC) (n = 51).

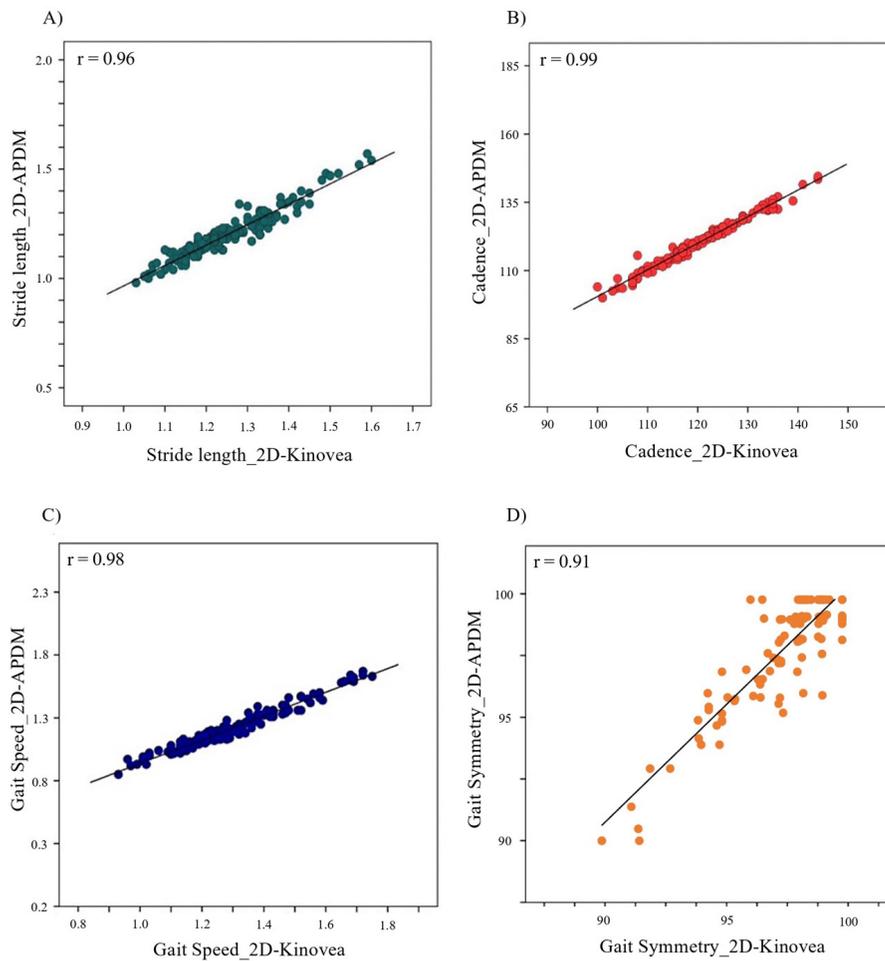
Variable	Mean <sub>APDM</sub>	Mean <sub>Kinovea</sub>	Mean diff <sup>a</sup>	95% LoA	PE <sup>b</sup> (%)	CCC (95% CI)
Stride length (meter)	1.20 ± 0.11	1.25 ± 0.11	0.05	-0.01 to 0.11	5	0.86 (0.83 to 0.89)*
Gait symmetry (%)	97.72 ± 2.28	98.12 ± 2.02	0.40	-1.54 to 2.34	2	0.89 (0.86 to 0.93)*
Cadence (step/minute)	119.97 ± 8.72	119.99 ± 8.85	0.02	-2.47 to 2.49	2	0.99 (0.98 to 0.99)*
Gait speed (meter/second)	1.21 ± 0.17	1.28 ± 0.17	0.07	0.01 to 0.15	5	0.88 (0.85 to 0.91)*

**Note:** <sup>a</sup>Mean diff: mean difference.

<sup>a</sup> Mean differences were derived from the formula as  $\text{Mean}_{\text{Kinovea}} - \text{Mean}_{\text{APDM}}$ .

<sup>b</sup> Percentage error was calculated as  $(100 \times (2\text{SD of bias}) / ((\text{Mean}_{\text{Kinovea}} + \text{Mean}_{\text{APDM}}) / 2))$ .

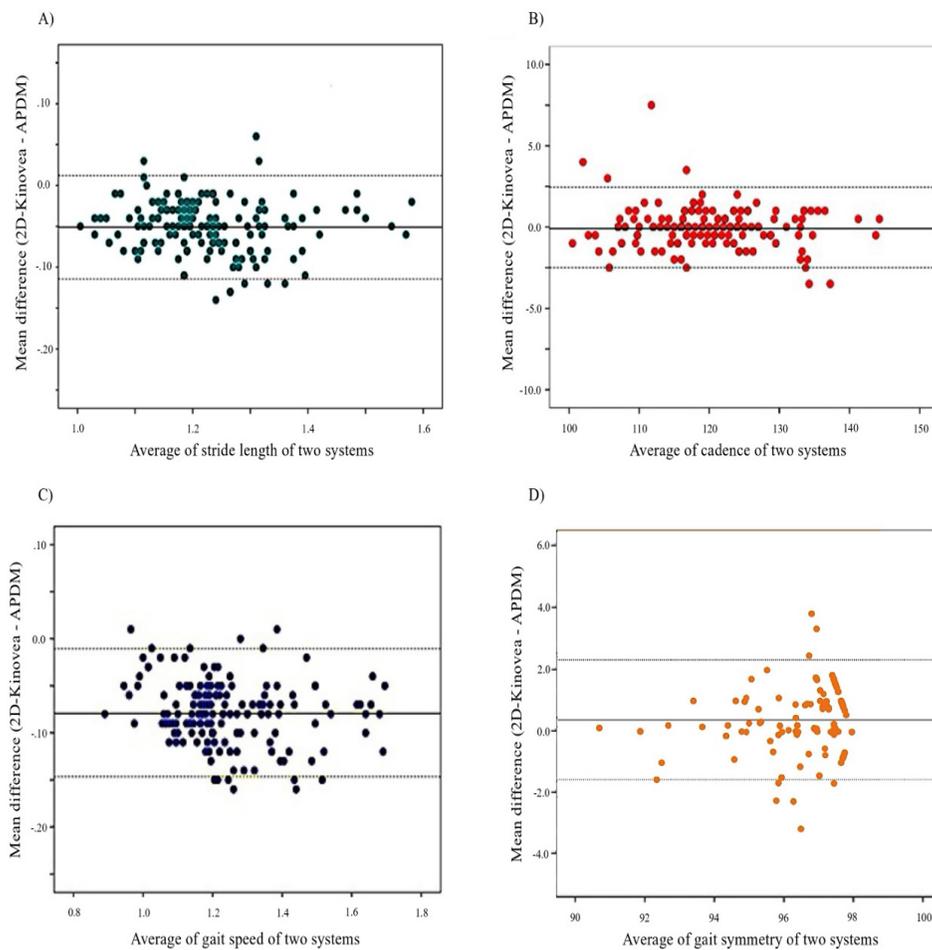
\*  $p$ -value < 0.001 from the concordance correlation coefficient.



**Figure 2** The correlation of spatiotemporal variables from 2D motion analysis (Kinovea) and inertial sensors (APDM) system using the Pearson's correlation (r) analysis.

- (A) Stride length
- (B) Cadence
- (C) Gait speed
- (D) Gait symmetry

**Abbreviations:** 2D-Kinovea, two-dimensional motion analysis using Kinovea; APDM, Inertial opal wearable sensor system.



**Figure 3** Bland-Altman plots comparing spatiotemporal parameters between 2D motion analysis (Kinovea) and inertial sensors (APDM) system.

- (A) Stride length
- (B) Cadence
- (C) Gait speed
- (D) Gait symmetry

**Abbreviations:** 2D-Kinovea, two-dimensional motion analysis using Kinovea; APDM, Inertial opal wearable sensor system.

## Discussion

Laboratory systems for spatiotemporal gait measurements are sophisticated, and thus they are costly and require experienced assessors, which limit their application to support current healthcare paradigm to distribute service to various settings<sup>(5,6)</sup>. Thus, recent research has been focused on validation and accuracy the

psychometric properties of 2D motion analysis to estimate gait parameters among several software<sup>(8,9,14)</sup>. However, the existing evidence that reported the validity and accuracy of Kinovea in measuring spatiotemporal gait parameters has been limited<sup>(15)</sup>. The current study found that the 2D-motion analysis using Kinovea is a valid and has acceptable interchangeability with inertial

sensor used in the current study (APDM) to assess spatiotemporal gait parameters, including stride length, gait symmetry, cadence, and gait speed during walking at a comfortable speed in healthy adults.

This study illustrated that Kinovea had extremely high correlation ( $r = 0.91 - 0.99$ ;  $p$ -value  $< 0.01$ ) and high acceptable agreement (CCC =  $0.86 - 0.99$ ; PE  $< 5\%$ ) to a criterion measure (APDM) for estimating gait parameters<sup>(7,19,27)</sup>. These findings provide clear data regarding the properties of Kinovea to measure spatiotemporal parameters that can be used as an alternative and surrogate method for spatiotemporal parameter measurement. A previous study examined the measurement properties between the 2D motion system using a 1-camera method and a gold standard 3D motion system, namely VICON<sup>(28)</sup>. They reported that the two systems had significantly different accuracies that were dissimilar compared to the current finding. However, one study examined the validity and agreement of SGAS software, which was in high agreement as compared to a criterion measure close to what we observed<sup>(8)</sup>.

However, the present study found that Kinovea has a lower agreement in spatial parameters (CCC =  $0.86-0.89$ ) than temporal variables. A plausible explanation for these findings may be due to a number of software and hardware factors, including (1) the irregular sampling rate of Kinovea, which typically is set at 30 frames/second, and (2) distortion in a simple lens possibly affecting the image shape, especially at the border, which could alter the appearance and perspective of video shots<sup>(29)</sup>. These factors may interfere with the pixel of the images, which could additionally affect the manual digitization process used to detect the spatial data of this study. Although the psychometric properties of 2D motion system using Kinovea to detect a stride length were lower than the other variables, they were still in an acceptable range for clinical and research application.

The current findings confirmed the use of Kinovea as a proxy 2D-spatiotemporal gait assessment among healthy adults. With its simplicity, the findings support the use of Kinovea to promote a standard screening and monitoring of gait parameter in various settings. However, there are some limitations in this study. The current findings did not cover all important spatial variables, especially a step length because the APDM's Mobility Lab system does not offer these data<sup>(30)</sup>. In addition, participants included only healthy adults, aged 18 to 59 years. As the gait variables are altered throughout lifespan and abnormality, a further study should explore clinical application of Kinovea covering all age groups, as well as those with pathologies affecting their gait manners.

## Conclusion

2D motion analysis using Kinovea is a valid and accurate system for assessing stride length, cadence, and gait speed while walking at a preferred speed of healthy adults. With its practicality, the present findings support the application of 2D gait assessments using Kinovea to facilitate standard screening with periodic monitoring for gait alteration in various clinical and research settings.

## Take home messages

2D gait analysis using Kinovea program provides valid and reliable spatiotemporal outcomes. As a simple and practical method, this system can be used to enhance standard screening with periodic follow-up for gait manners in various clinical and research settings.

## Conflicts of interest

The authors declare no conflict of interest.

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