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A Simple and Objective Method for Analyzing a Gymnastics Skill

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Abstract

The traditional approach to evaluate gymnastics by subjective rating requires an experienced eye, posing challenges to teachers and coaches who may not have the necessary personal experience. This study presented a simple and objective method for analyzing a dynamic, asymmetrical and multi-planar gymnastics skill (cartwheel). Two studies were conducted to analyze videos of cartwheel performances by quantifying ankle, knee, hip, shoulder, and torso angles using an open source freeware. Study 1 tested whether the method could differentiate between highly trained gymnasts and novices, and assessed the reliability of the method. Study 2 evaluated whether the method could track the progression of novice learners: Performances of an experimental and a control groups were compared before and after a 20-minute intervention. Results showed excellent intra- and inter-rater reliability (intra-class correlation > 0.90, standard error of measurement < 5°). Highly trained gymnasts displayed better forms than novices at the ankle, knee, shoulder and torso (all $p < 0.05$). After brief practice, novel learners showed improvements at the knees ($p = 0.007$) and ankles (group × time $p = 0.05$) when performing a cartwheel. In conclusion, the proposed video analysis method demonstrated good potential for assessing the cartwheel in a simple and objective way.

Keywords: cartwheel, video analysis, reliability, skill level, learning.

1. Introduction

Gymnastics is a core component in physical education (PE) programmes and extra-curricular activities in many education systems worldwide (Napper-Owen et al., 1999; Pajek, Tursic, 2010; Quill, Clarke 2005). Assessment of a gymnastics skill is generally performed by a teacher, coach, or judge, who rates the skill according to its aesthetic appeal as it is executed (Hein, Kivimets, 2000; Heinen et al., 2009; Sadowski et al., 2009; Smith et al., 2003). The aesthetic appeal of gymnastics is closely related to movement form such as pointing the toes and extending the knee. Evaluation of gymnastics by rating, though commonly practiced, is highly subjective and requires an experienced eye to evaluate the skill quickly and accurately (Pizzera, 2012). This poses challenges to many PE teachers and some coaches who may not have the necessary gymnastics background to identify performance errors based on personal experience (Ste-Marie, 2000).

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To overcome the problem of subjectivity and the lack of experience, biomechanical analysis can provide an objective and precise solution to evaluate gymnastics skills through the use of videos, motion capture system and computational analysis software. For example, motion capture systems which track the trajectories of retro-reflective markers placed on the body have been used to analyze gymnastics' high bar performance (Cagran et al., 2010; Hiley et al., 2007). Video analysis coupled with force measurements provided insight into the technique of the circles on pommel horse (Fujihara et al., 2009). Good attempts have been made to incorporate biomechanics in judging gymnastics by use of video analysis, timing gates and computer algorithm (Sands, McNeal, 1999). Recently, a new algorithm was proposed to automatically recognise body movements from video recordings with an aim to aid scoring of rhythmic gymnastics movements (Díaz-Pereira et al., 2014). The scores computed by the algorithm were comparable to those assigned by expert judges for a few standard gymnastics movements. However, these biomechanical and computational approaches often require specialised equipment and are too complex and time consuming for teachers and coaches to incorporate into their practices. Thus, simpler quantitative analysis methods will better assist PE teachers and gymnastics coaches to identify and correct performance errors. Simple evaluation methods can also offer an opportunity for students to perform self-check and peer assessment to enhance learning experience in cognitive, psychomotor and affective domains (Baumgarten, Pagnano-Richardson, 2010; Johnson, 2004; Nilges-Charles, 2008).

The use of simple two-dimensional (2D) video analysis has proved to be a promising alternative for evaluating gymnastic movements effectively. Siatras (2011) presented a technique of skill analysis by measuring body segmental angles during a static strength element (V-sit) using digital photography and computer-aided image analysis. Rosamond and Yeadon (2009) utilized 2D video analysis of the backward handspring to design a safe and practical training aid to assist skill learning. These previous studies, however, analysed only static positions (e.g. V-sit) or bilaterally symmetrical movements that occur in one plane (e.g. back handspring). Since many gymnastics movements are dynamic, asymmetrical, and multi-planar in nature, there is a need to develop user-friendly methods for quantitative analysis of more complex skills. Such methods can support student learning by using technology to provide feedback and to document improvement over time (Bonnie, Thompson, 1997)

Therefore, the aim of this study was to develop a simple and objective method to analyze a dynamic, asymmetrical and multi-planar gymnastics skill – the cartwheel. The cartwheel was chosen to illustrate this method because (a) it is an asymmetrical skill that occurs in multiple planes, (b) it is a skill frequently taught in PE curriculum in schools, and (c) it is a common fundamental skill in many acrobatic activities including gymnastics, dance and martial arts. The proposed method would involve affordable equipment and straight forward analysis procedures to evaluate cartwheel performances. It was hypothesized that this method would be sufficiently reliable, and able to differentiate various skill levels as well as to track learning progression among novices.

2. Methods

Two studies were conducted to develop and to evaluate a video analysis method. Ethical approval was obtained from the university research ethics committee. Prior to any procedures, all adult participants provided written informed consent. For minor participants, written parental consent together with minor ascent were obtained.

Study 1: Differentiating skill levels

This study was designed to test whether the proposed video analysis method could successfully differentiate various skill levels. The cartwheel performances between highly trained and novice gymnasts were compared. Since differences in performance were expected between these two groups, this comparison served to examine whether the proposed method was effective in identifying the expected differences.

Participants. Five male national-level gymnasts [Mean (*SD*) age = 23.8 (8.4) years, height = 1.69 (0.05) m, body mass = 64.8 (6.6) kg] and 17 novices with little or no prior gymnastic experience [13 men, 4 women, mean (*SD*) age = 24.9 (4.7) years, height = 1.70 (0.07) m, body mass = 65.3 (9.3) kg] were recruited to participate in the study. The highly trained gymnasts have had at least seven years of training experience and competed at national or international levels.

*Procedures***.** After performing self-selected warm-up, the participants were instructed to perform a cartwheel starting from a standing position. A single camcorder (Sony DSR-PD170P) was used to record the cartwheel performances at a frame rate of 50 Hz. The camcorder was positioned at the end of the mat along the direction in which cartwheel was performed (see Figure 1(a)). This camera position was set to capture the side view of the participants when they were near an inverted position during a cartwheel (see Figure 1(b)). No calibration procedures were required. Only one trial was recorded per participant to replicate a realistic PE lesson in which a teacher may need to evaluate over 40 students within 50 minutes (excluding post-possessing time).

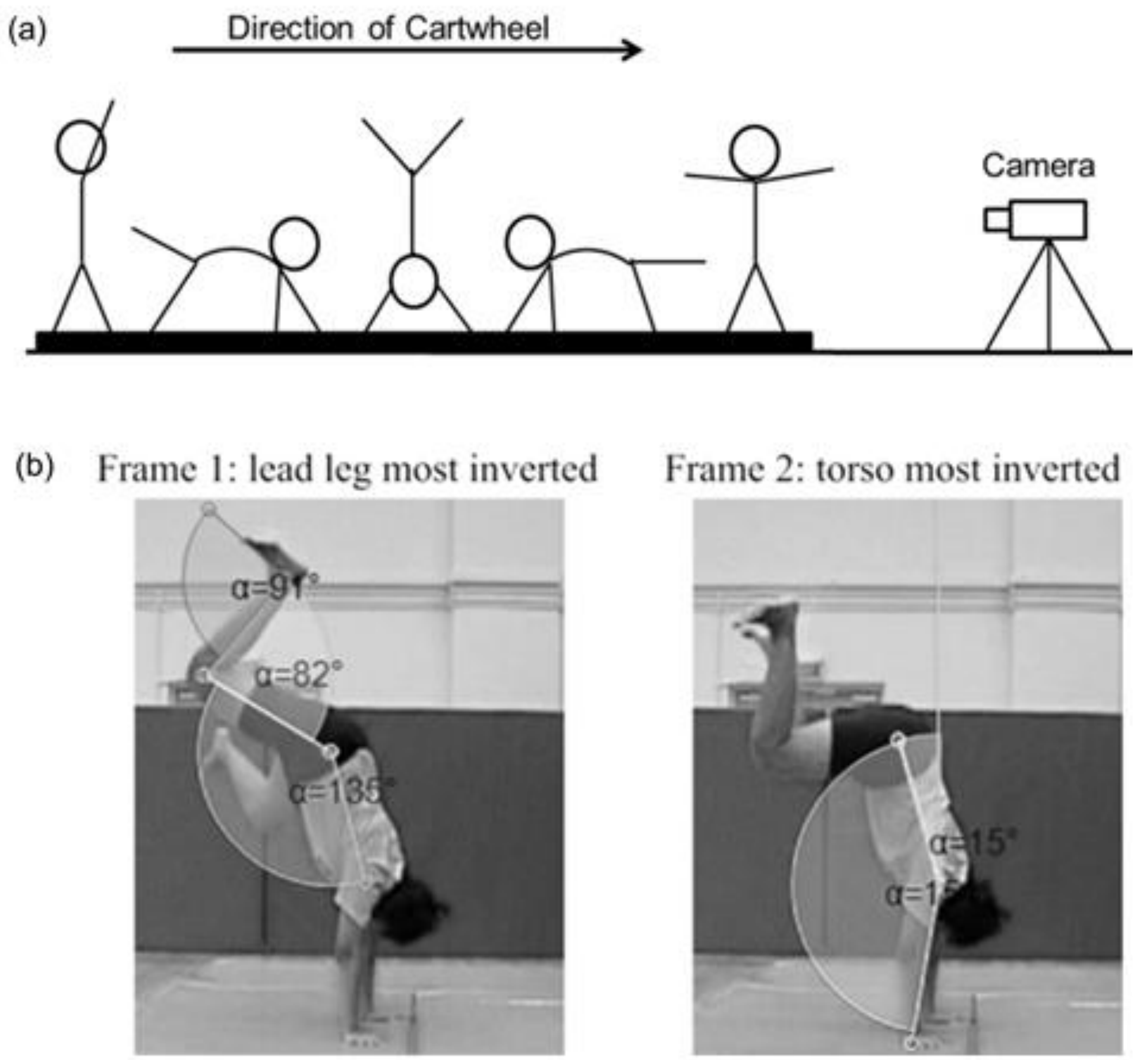

Figure 1. (a) Experimental set-up for video recording of cartwheel performances with a single camera. (b) Cartwheel videos were manually digitized in two selected frames. Frame 1: the lead leg was most inverted (measurement of ankle, knee and hip angles). Frame 2: the torso was most inverted (measurement of the shoulder and torso angles).

The videos were then analyzed using an open source freeware for motion analysis. Two frames in each video recording were selected for manual digitization – frame 1 at which the leading leg was most inverted and frame 2 at which the torso was most inverted (see Figure 1(b)). In frame 1, the participant's ankle, knee, and hip joint angles were measured by digitizing the toes and the joint centers of the knee, hip, and shoulder. In frame 2, the shoulder joint angle and the degree of tilt of the torso from the vertical were also measured. The time at which frame 1 and frame 2 occurred were also recorded. Selection of these two frames allowed simple 2D video analysis for a multi-planar movement because the body angles to be measured can be assumed to lie in a plane perpendicular to the optical axis of the camera. We chose to analyze only absolute (torso) or relative (ankle, knee, hip and shoulder) angles but not spatial variables (e.g. distance) so that no calibration was required. These procedures involve basic and affordable equipment, free computer software, and minimal manual processing of data.

Reliability. To assess intra-rater reliability, all 22 videos were digitized twice by the same rater (Rater 1) with an interval of seven days between repeated digitization. This rater has a degree in sports science and no formal training in gymnastics. The videos were also digitized by two other raters (Rater 2 and Rater 3) independently for the inter-rater reliability analysis. Rater 2 was a former gymnast in the junior national team. Rater 3 did not have any gymnastic experience and could not perform a cartwheel. The purpose of the study was blinded to all raters to avoid bias.

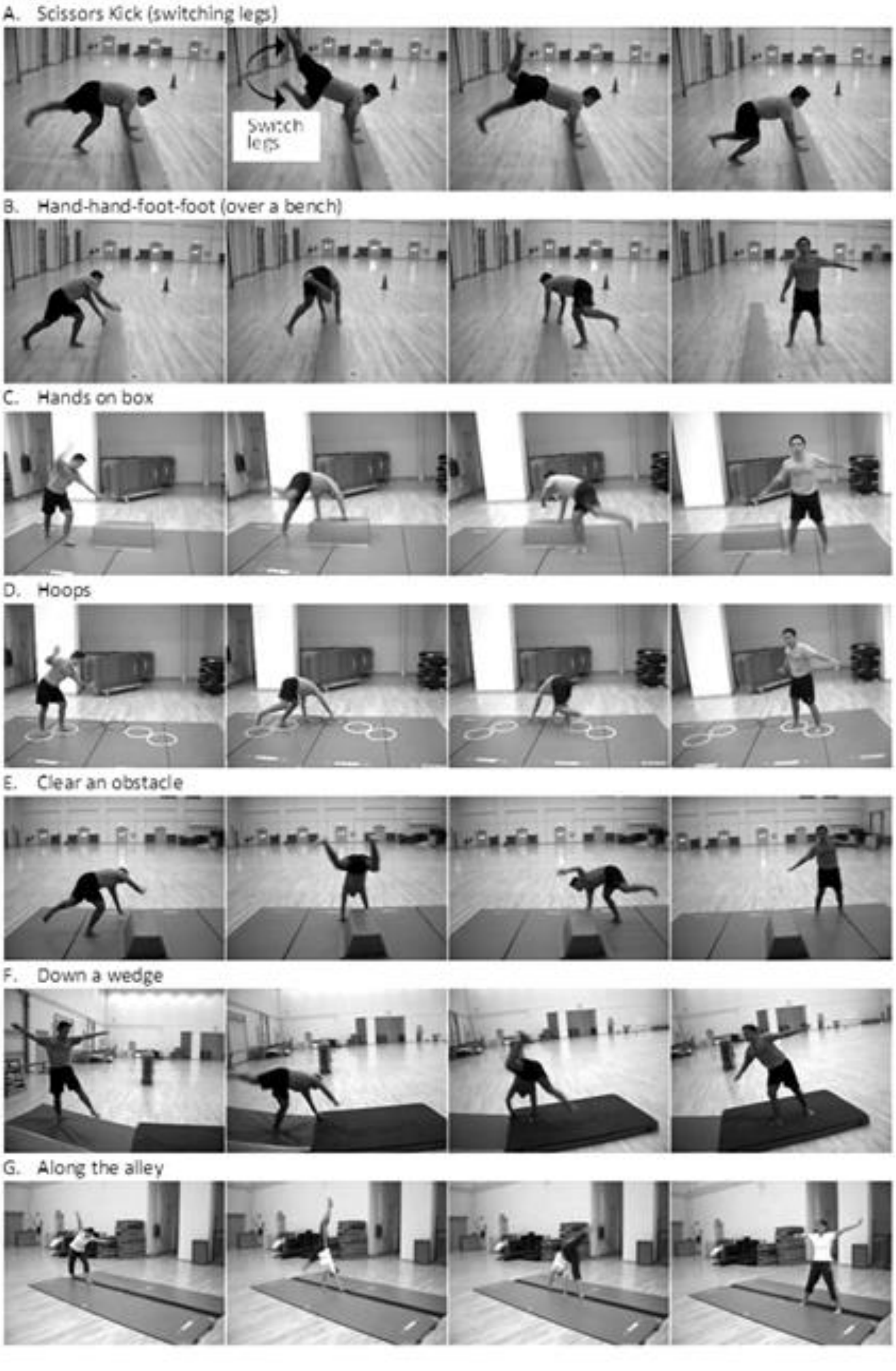

Figure 2. Participants in the experimental group (n = 9) practiced seven drills to promote better cartwheel techniques during a 20-minute intervention

Study 2: Tracking learning progression

This study was designed to evaluate whether the proposed video analysis method could identify changes in performance with learning. Cartwheel performances of novices were compared before and after an intervention comprised of cartwheel-related or other gymnastics drills.

Participants. Seventeen novices were conveniently sampled from a group of trainee teachers enrolled in a 'Curriculum Gymnastics' module. The participants were randomly assigned to an experimental [*n* = 9, 5 men and 4 women, mean (*SD*) age = 24.3 (4.3) years, height = 170.1 (7.8) cm, body mass = 65.0 (10.1) kg] and a control [*n* = 8 males, mean (*SD*) age = 25.6 (4.8) years, height = 170.3 (5.3) cm, body mass = 65.6 (7.6) kg] groups. All participants had minimal experience in gymnastics.

Procedures. The equipment and set-up were identical to those described in Study 1. After warming up, all participants performed a cartwheel from a standing position and their movements were recorded by a camcorder (pre-intervention). Thereafter, participants were split into their corresponding groups for 20 minutes of practice before performing another cartwheel for the post-intervention analysis. This intervention duration of 20 minutes replicates the activity time available in a single lesson period (approximately 30 minutes) in most schools in Singapore.

Participants in the experimental group practiced seven cartwheel-related drills (see Figure 2) in rotational sequence, for a total of 10 minutes. They were then given 10 more minutes to practice any of these drills of their choice. These drills were specifically designed to improve the cartwheel movement by emphasizing various important elements, such as extending the hips, correct sequencing and positioning of the hands and feet, and getting the torso to an inverted vertical position. Similar drills have been used in previous research to facilitate learning of a cartwheel among participants with no gymnastics experience (Smith et al., 2003). Participants in the control group were given 20 minutes to practice five general gymnastics drills in rotational sequence – handstand facing the wall, balancing along an inverted bench, forward or backward rolls down an inclined wedge, tripod stand or half headstand, and a mini-routine involving balance and roll elements. After the 20-minute intervention, the cartwheel performances of participants from both groups were video recorded again.

All cartwheel videos were digitized by Rater 1 using the same procedures described in Study 1. In order to prevent bias, the study design and the assignment of participants to the experimental or control groups were unknown to the rater.

Statistical analysis

Statistical analysis of data was done using IBM SPSS Statistics 21 (Chicago, IL) and Microsoft Excel. There were five dependent variables, comprising the ankle, knee, hip, shoulder and torso angles. Inter-rater and intra-rater reliability were evaluated using intra-class correlation (ICC) values, standard errors of measurement (SEM) values and Bland and Altman plots. The times at which frame 1 and frame 2 were identified were also compared within and between raters. For Study 1, the Mann-Whitney U test was used to compare the cartwheel performances between the highly trained gymnasts and the novices. For Study 2, a 2 × 2 (group × time) Analysis of Variance with repeated measures was used to examine the effect of practicing cartwheel drills on each of the selected angles. The within-group factor was time (pre versus post) and the between-group factor was group (experimental versus control). Data are presented in means (standard deviations). Statistical significance was set as 0.05 throughout.

3. Results

Reliability analysis

Intra-rater reliability was excellent (ICC = 0.96 to 1.00, SEM = 1° to 3°, see Table 1). Rater 1 was very consistent in the identification of frames 1 and 2 – the exact frames were selected on both days in 32 out of 44 trials, and the remaining 12 trials differed by just 1 frame (0.02 s). Furthermore, a visual inspection of the Bland Altman plots showed random scatter of the points between the limits of agreement, indicating homoscedastic data as well as an absence of systematic bias (see Figure 3).

Table 1. Intra- and Inter-rater Reliability of Video Analysis of Cartwheel Performances

Angles		Mean (day 1)	Mean (day2)	Mean difference	ICC	SEM	95% Limits of Agreement	
							Lower	Upper
Ankle	Intra-rater	126	125	-1	0.98	3	-10	8
	Inter-rater	129	/	/	0.95	5	/	/
Knee	Intra-rater	149	148	-1	1.00	2	-5	5
	Inter-rater	147	/	/	0.99	3	/	/
Hip	Intra-rater	172	173	1	0.97	3	-8	9
	Inter-rater	171	/	/	0.92	5	/	/
Shoulder	Intra-rater	153	152	-1	0.96	3	-10	7
	Inter-rater	155	/	/	0.92	5	/	/
Torso	Intra-rater	17	17	0	0.99	1	-4	4
	Inter-rater	15	/	/	0.93	3	/	/

Note. Mean difference was calculated from day 2 – day 1. ICC = intra-class correlation, SEM = standard error of measurement.

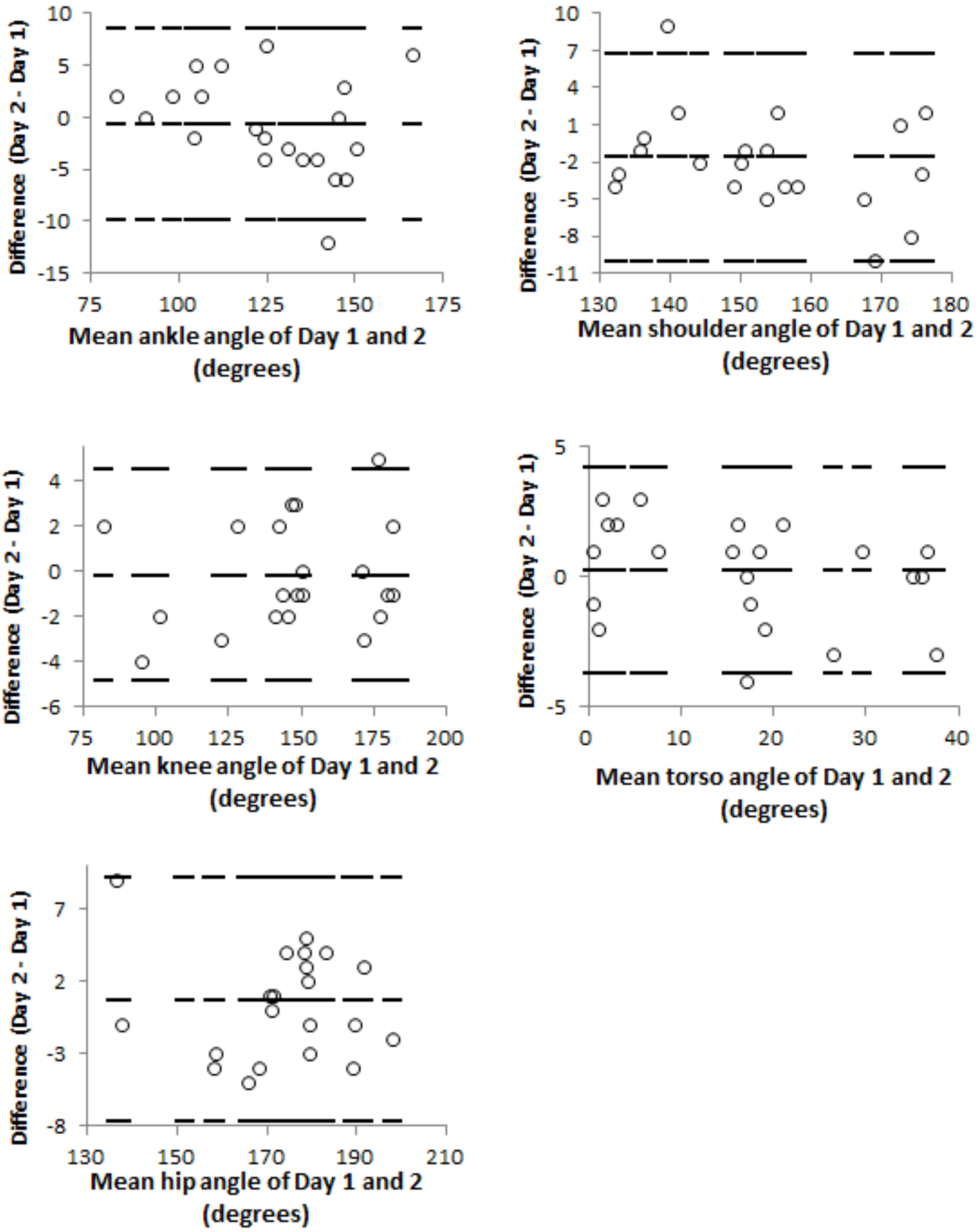

Figure 3. Bland-Altman plots for the ankle, knee, hip, shoulder and torso angles digitized seven days apart by the same rater.

Inter-rater reliability was also excellent (ICC = 0.92 to 0.99, SEM = 3° to 5°, Table 1). Regarding the identification of frames 1 and 2, the exact frames were selected in 16 out of 44 trials among the three raters with varied gymnastics abilities. The selection of frames generally differed by 1 to 2 frames (0.02 to 0.04 s). Only 2 out of 44 trials had the maximum discrepancy of 3 frames (0.06 s) among the raters.

Study 1: Differentiating skill levels

The Mann-Whitney U test revealed significant differences ($p < 0.05$) between the two groups of participants of different skill levels in all measured angles except the hip (see Table 2). Compared to the novices, the highly trained gymnasts are characterized by more pointed toes, greater extension at the knee, greater flexion at the shoulder as well as a more inverted torso.

Typical cartwheel performances of a highly trained gymnast versus a novice at the two selected video frames are compared in Figure 4.

Table 2. Comparison of Cartwheel Performances [mean (standard deviations)] between highly trained gymnasts and novices

Angles	Highly Trained Gymnasts (degrees)	Novices (degrees)	Statistical Results
Ankle	151 (7)	117 (20)	U = 1.50, Z = -3.18, *p* = 0.001*
Knee	177 (4)	137 (26)	U = 4.50, Z = -2.93, *p* = 0.003*
Hip	180 (11)	169 (17)	U = 26.50, Z = -1.26, *p* = 0.209
Shoulder	174 (3)	147 (13)	U = 2.00, Z = -3.18, *p* = 0.001*
Torso	1 (1)	21 (12)	U = 4.50, Z = -2.98, *p* = 0.003*

*Statistical significant differences (p < 0.05).

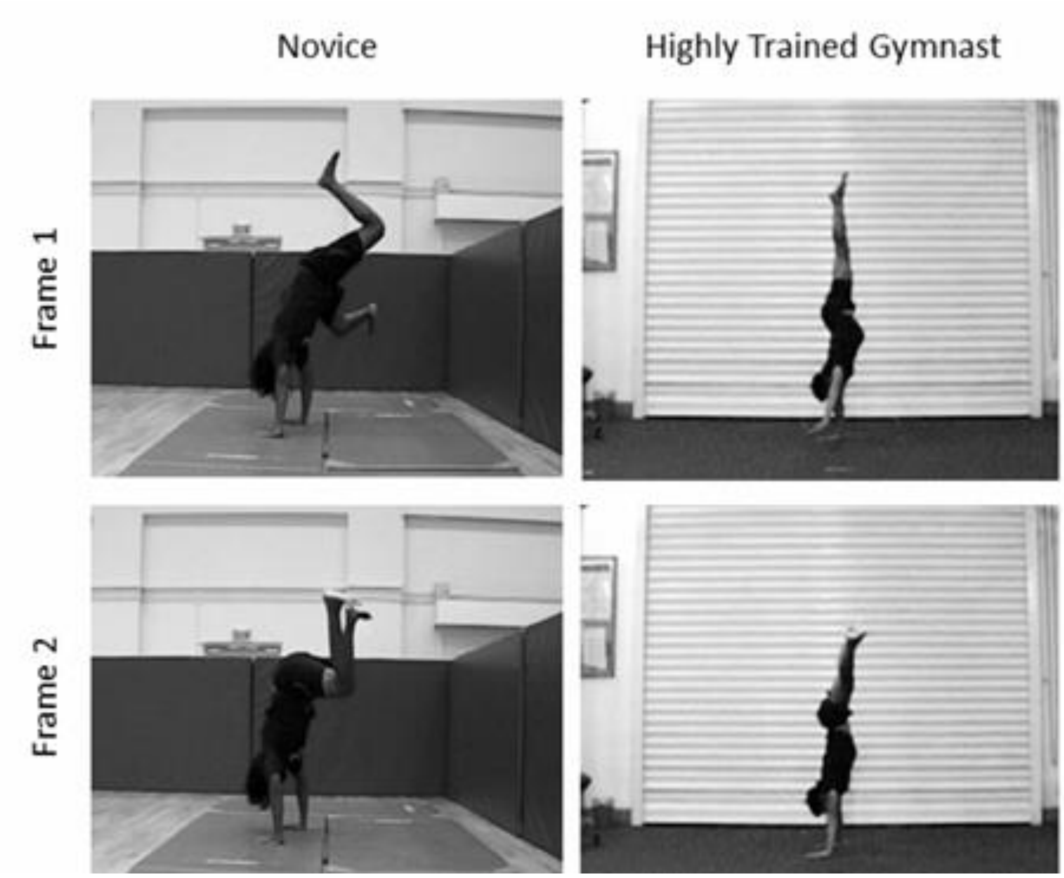

Figure 4. Comparison of cartwheel performances between a typical novice and a highly trained gymnast at two selected frames for digitization (frame 1: leading leg most inverted, frame 2: torso most inverted).

<u>Study 2: Tracking learning progression</u>

Analysis of Variance revealed no differences in all measured angles between the experimental and control group (see Table 3). After the intervention, participants from both groups showed significant improvements in extending the knee (p = 0.007). For the ankle angle, there was a significant group × time interaction (p = 0.05) with improvements in pointing the toes only seen in the experimental group but not the control group. Individual plots of the changes in angles before and after the intervention are shown in Figure 5.

Table 3. Comparison of Cartwheel Performances [mean (standard deviations)] Pre- and Post-Intervention

Angles		Control (degrees)	Experimental (degrees)	*p*-values Group	Time	Group × Time
Ankle	Pre	122 (6)	115 (8)	0.833	0.035*	0.050*
	Post	123 (8)	134 (8)			
Knee	Pre	133 (13)	140 (7)	0.827	0.007*	0.344
	Post	152 (10)	150 (7)			
Hip	Pre	167 (8)	170 (5)	0.860	0.184	0.830
	Post	172 (7)	173 (5)			
Shoulder	Pre	143 (7)	148 (3)	0.275	0.588	0.190
	Post	141 (7)	153 (3)			
Torso	Pre	24 (5)	19 (3)	0.199	0.128	0.274
	Post	23 (5)	14 (2)			

*Significant main effect detected by Analysis of Variance ($p < 0.05$)

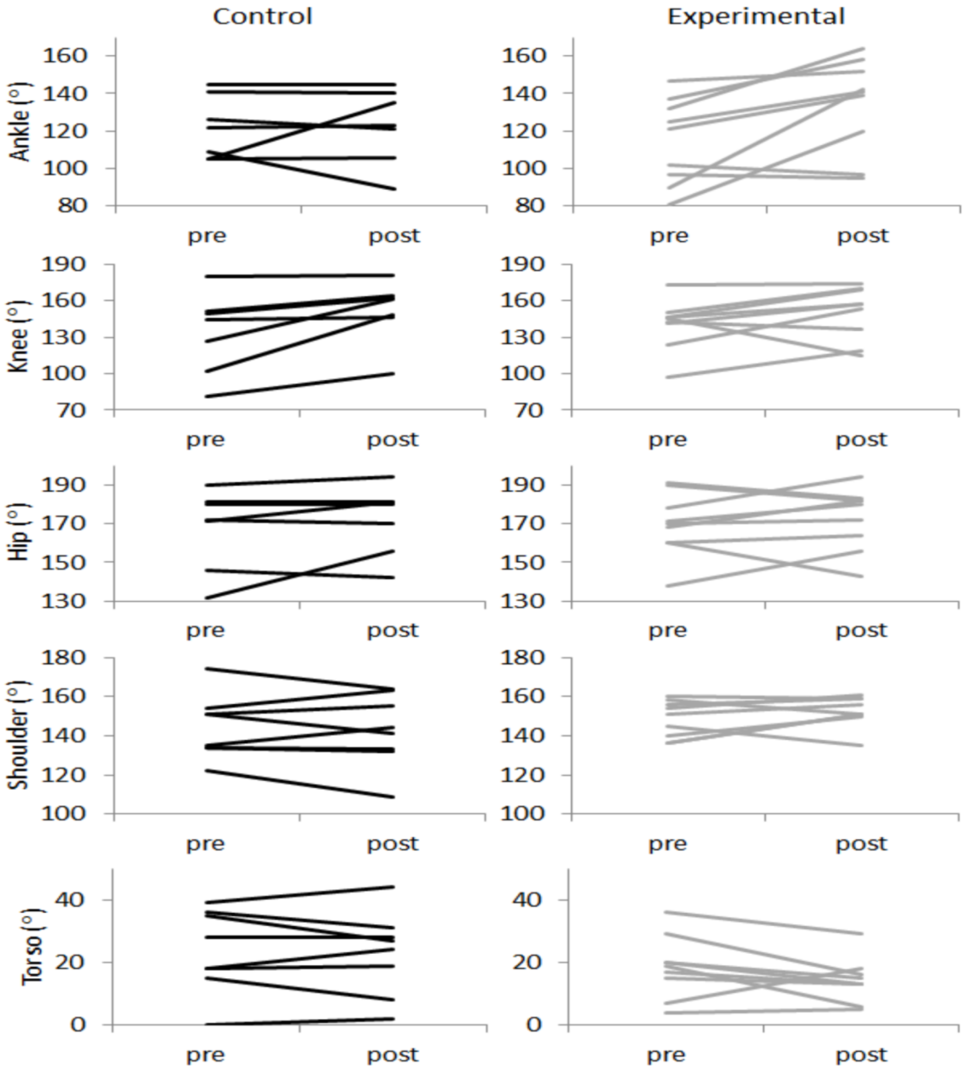

Figure 5. Changes in angles of individual participants (experimental n = 9, control n = 8) before and after a 20-minute intervention.

4. Discussion

This study presented a new method of analysing a dynamic, asymmetrical and multi-planar gymnastics movement using affordable equipment, free computer software, and simple processing procedures. As hypothesized, this objective method has shown to be reliable and effective in differentiating between different skill levels as well as tracking learning progression.

The intra-rater and inter-rater reliability analyses revealed excellent repeatability overall, with very few discrepancies in the identification of the required video frames. The good agreement among the three raters with different gymnastics abilities suggests that the proposed method can be readily adopted by coaches, teachers and students regardless of their personal experience. While the use of holistic rubrics remains a sound and effective way in assessing gymnastics (Johnson, 2004; Nilges-Charles, 2008), the simple analysis method proposed in this study provides an alternative means to support teacher, self and peer assessment. The use of video technology in PE and sport settings can overcome the limitation of subjective judging which requires one's own sensorimotor experience to accurately assess the complex movement patterns in gymnastic skills (Pizzera, 2012) and also provide students with opportunity to receive feedback and reflect on their performances (Mohsen & Thompson, 1997). Given that only basic equipment and simple procedures are needed to perform the proposed video analysis, PE teachers and coaches can easily engage students to do self or peer evaluation. Involving students in assessment will not only reduce the burden on the teachers and coaches but also enhance student learning experience (Johnson, 2004; Nilges-Charles, 2007). In a study of selected gymnastics skills (handstand, forward and backward rolls), it has been proposed that including additional students in the evaluation process can raise the objectivity of the ratings (Rasidagic, 2014). Considering the rapid development of mobile phone technology in recent years, many students may have access to a phone which can record high quality videos. There are also free or affordable apps which allow frame-by-frame video analysis including the 2D angles proposed in this study. Thus, it deems plausible to incorporate simple video analysis in the teaching and assessment of gymnastics.

There were marked differences in the cartwheel techniques between the highly trained gymnasts and the novices, as noted in most measured angles (see Table 2). This supports that the proposed method is effective in differentiating gymnastic techniques performed by individuals at varied skill levels. It is interesting to note that no differences in the hip angles were found between the two groups, suggesting that perhaps the hip is the easiest joint for novices to extend when performing a cartwheel. Teachers and coaches may consider drills that emphasize correction of movement errors in other joints when teaching beginning learners.

Monitoring learning progression of a skill is important for PE teaching and coaching. Using the proposed video analysis method, we noted improvements in the ankle and knee after one session of intervention (see Table 3). With 20 minutes of practicing cartwheel-related drills, participants performed a cartwheel with more pointed toes and straighter knees. It should be noted that the control group also displayed more extended knee angles at the post-test. This was somewhat unexpected and may be related to the choice of drills in the control group. For example, practicing the handstand facing the wall may have promoted a straighter knee when performing a cartwheel later on. We also allowed a free choice of a balance element during the mini-routine and participants may have selected a skill that emphasizes a straight leg posture (e.g. Arabesque, Y-balance). No change in the hip, shoulder, and torso angles for both experimental and control groups were found. As noted earlier in Study 1, there was no difference in hip angles even between highly trained and novice gymnasts. Thus, one would not expect further improvements in the hip angles for the novices after the cartwheel intervention. For the shoulder and torso angles, the entire body needs to approach an inverted position for good performance. Given the difficulty of achieving an inverted orientation, the 20-minute duration of the intervention might have been insufficient for the novices to make noticeable improvement in the shoulder and torso angles. Future studies could follow the learning process for a longer duration, preferably over multiple intervention sessions, to confirm the typical time required for novices to master the skill. From a methodological perspective, there is some potential to use the proposed video analysis to monitor the learning progression of dynamic, asymmetrical and multi-planar gymnastics skills.

There are a few limitations to this study. First, the proposed analysis method only assesses the cartwheel performances of the participants from the side view in two video frames. We acknowledge that the restricted viewing position has limited the representativeness of an information sample (Plessner, Haar, 2006) and therefore does not provide a holistic assessment of the entire cartwheel movement in the same way that a judge, coach or teacher may evaluate the skill. The current method does not include other criteria that are considered important for good performances, for example, placement of hands and feet in a straight line (Smith et al., 2003). Second, only one trial was recorded per participant to resemble the time allowed in a typical PE lesson. Given the large variance in performance for beginning learners, we acknowledge that the recorded trial may not be representative of the learning progress. Future studies can examine the number of trials required for performance to be stabilized. Such knowledge may further enhance the reliability of the proposed method. Third, we showed that the method could differentiate between highly trained gymnasts and novices but most PE teachers do not work with national athletes. A meaningful extension to this study will be to examine if the proposed method can differentiate among a larger sample of novices, especially school children. Finally, the feasibility and effectiveness of applying the proposed method in peer assessment for enhancing learning warrant further investigation.

5. Conclusion

This study proposed a simple video analysis method to analyze the cartwheel, a dynamic, asymmetrical and multi-plane skill. With excellent intra- and inter-rater reliability, this method can successfully differentiate gymnasts of varied skill levels and demonstrate potential to track the learning progressions of novices. This 2D video analysis method requires only affordable equipment and simple procedures, making it a practical way for coaches, teachers and students to evaluate gymnastics movements objectively. The good agreement among the raters with different gymnastic abilities suggests that the proposed method can be readily adopted by coaches, teachers and students regardless of their personal experience.

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