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Original Article

Centre of Mass Position in Gymnastics Balances – Are the Textbook Illustrations Correct?

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Abstract:

This study examined if the centre of mass (CM) position of static balances in gymnastics textbooks were correctly illustrated. Out of 108 gymnastics textbooks screened for figures that illustrated CM positions in static balance postures, 33 images from four textbooks were retrieved for analysis. In each image, the actual CM was calculated using the segmentation method based on measured segmental lengths and body segmental inertial parameters. The offset distance between the illustrated and calculated CM was quantified to indicate the accuracy of the book illustration. To facilitate comparisons among images of different sizes, the offset distance was normalised to the leg length of the body as a percentage error. An error of less than 10% was considered small, 10 to 20% moderate, and greater than 20% large. Results showed that the average error was 12.8% (ranging from 0% to 39.0%). The error was small in 17 (52%) images, moderate in 11 (33%) images, and large in 5 (15%) images. Calculated CM were often (26 out of 33, or 78.8%) superior to the illustrated positions. One common misconception was that the illustrated CM tended to lie within the body in postures where the calculated CM was outside the body (e.g. half headstand, seated pike stretch). These incorrect CM illustrations and concepts in gymnastics textbooks may misguide the pedagogical practices for physical education teachers and coaches. To better reflect the true CM of gymnastics postures, future reference materials should incorporate anatomical and biomechanical expertise in the preparation of figures.

Key Words: - centre of gravity, body segmental inertia, biomechanics, segmentation method, static, educational gymnastics

Introduction

Static balance is a key component in educational gymnastics that is widely taught in kindergartens, primary schools, and secondary schools across many countries. Good balance performance requires one to control the centre of mass (CM) position within the base of support (Robertson, 2013). The CM is defined as the average location of all masses in a body, while the base of support refers to the area covered by the outermost parts of a body which is in contact with a particular supporting surface.

Understanding of the CM position in various postures can facilitate Physical Education (PE) teachers and coaches to provide correction and feedback to a student's movement (Smith, 1982). Good knowledge in the mechanical principles of CM position in relations to the base of support can guide teachers and coaches to make decisions on teaching progression. For example, the difficulty of an inverted balance increases from tripod stand to half-headstand because the CM position is rising higher while the base of support remains the same. Teachers and coaches can make appropriate modification to adjust the CM position or/or base of support to suit students' individual need. As students perform balances or transit in movement from one balance to another movement, awareness of their own CM position would be an integral factor which influences their performance (Page, 1974). Educational gymnastic textbooks make up one of the core resources for teachers and coaches to obtain knowledge and to learn how to teach particular gymnastics balances. Gymnastic textbooks often include performance cues, sample of activities, and illustrations of balances accompanied with CM position. The illustrated CM position in the textbooks, however, may not accurately reflect the true CM position if the authors and/or illustrators do not have the necessary anatomical and biomechanical expertise in calculating the CM position using scientific methods.

Given that many PE teachers and coaches make reference to textbooks, incorrect illustration of CM positions can misguide their teaching strategies and decision making and hence negatively affect student learning. Thus, it is important to evaluate the accuracy of CM positions illustrated in textbooks. The objective of this study was to examine if the CM position of static balances in gymnastics textbooks were correctly illustrated.

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Material & methods

Search strategy

A systematic search of the literature in educational gymnastics was performed using the library system provided by the National Institute of Education, Singapore (Fig. 1). First, an online search using SPORTDiscus and Google Scholar was conducted with the following search terms: gymnastic / teach / education / coach / balance. Next, items that fulfilled the following two criteria were selected: 1) Books that contained figures of static gymnastic balances with CM indicated on the figure; and 2) Books that were related to educational gymnastics or coaching of youths. The exclusion criteria were books that were not educationally themed (e.g. historical or narratives), or did not contain any images or illustrations of balance positions. A total of four textbooks were selected from this phase (Broomfield, 2011; Cooper & Trnka, 1994; Schembri, 1983; Smith, 1982). In these four selected textbooks, images of static balance positions with at least one body part in contact with the ground surface were included for analysis. Balance positions with equipment such as the pommel horse, vaults, rings, or bars were excluded. Dynamic movements and still-images in flight were also excluded. A total of 33 images were selected, including 4 images from Book 1 (Broomfield, 2011), 8 images from Book 2 (Smith, 1982), 14 images from Book 3 (Schembri, 1983), and 7 images from Book 4 (Cooper, 1994).

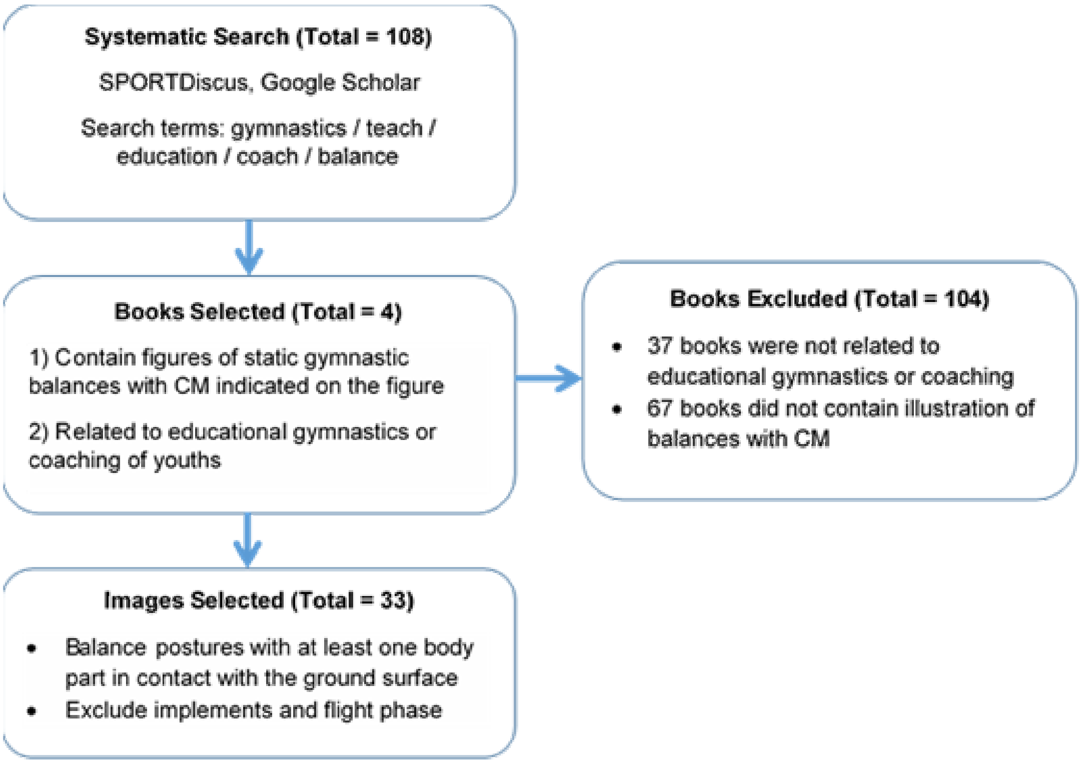

Fig. 1. Systematic search of gymnastics textbooks and extraction of images

Calculation of CM

The true CM position of the each of the 33 extracted images were calculated using the segmentation method typically used in the field of sports biomechanics (Knudson, 2007). This method determines the location of a body's CM from the CM of each individual segment of the body (e.g. head, trunk, arm, leg) using anthropometric data and mathematical equations.

First, each image was enlarged to A4 size on a piece of paper with x and y-axes. Second, 14 body segments were manually identified: Head, trunk, right thigh, right shin, right foot, left thigh, left shin, left foot, right upper arm, right lower arm, right hand, left upper arm, left lower arm, and left hand. The segments begin and end at anatomical landmarks that were approximated on the image. Third, segmental inertial parameters including the location of the CM of each segment and the relative percentage of mass with respect to the total body were obtained from the literature (Jensen, 1986). We adopted the data from Jensen's (1986) study because these parameters were primarily determined from children and youths. Selecting parameters closely matching the population (children) observed would provide a more accurate approximation of the CM (Hay, 1973). Fourth, to obtain the coordinates for the total body's CM, the following formula were used;

$$x_{CM} = \Sigma(m_i D_x) / m \qquad (1)$$

$$y_{CM} = \Sigma (m_i D_y) / m \qquad (2)$$

where x_{CM} and y_{CM} are the coordinates of the total body CM, m_i is mass of individual segments, the D_x and D_y are coordinates of the individual segment CM, and m is the total body mass. Finally, the calculated x_{CM} and y_{CM} coordinates would then intersect to indicate the CM on the image.

Scaling and Error Calculation

To evaluate the accuracy of the illustrated CM in the textbooks, the offset distance between the illustrated and calculated CM was measured (Fig. 2). Since the images differ in size, it is necessary to scale the offset distance in proportion to the size of the gymnast illustrated, in order to allow fair comparisons among images. Thus, the offset distance was normalised to the leg length of the body measured from hip to ankle (Fig. 2). For images where a straight leg length could not be measured directly (e.g. postures with flexed knees), the shin length (knee to ankle) was determined and scaled to leg length using Robinow's (1982) ratio of children's tibia length to leg length. The normalised offset distance between the calculated and illustrated CM positions were expressed as a percentage error (100% = leg length in actual distance). To categorise the magnitude of the differences, an error of less than 10% was considered small, 10 to 20% moderate, and greater than 20% large.

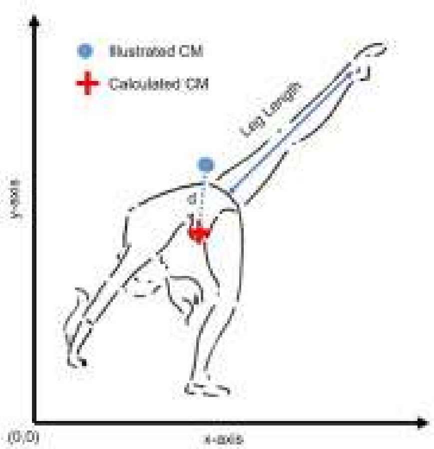

Fig. 2. Offset distance (d) between the calculated and illustrated centre of mass (CM) positions was normalised to leg length (hip to ankle) to allow fair comparisons among images of different sizes.

Results

On average, the error of the illustrated CM positions was 12.8% across all 33 images (Book 1: 14.4%, Book 2: 7.1%, Book 3: 13.5%, Book 4: 15.2%). The errors were small in 17 (52%) images, moderate in 11 (33%) images, and large in 5 (15%) images (Table 1). Some examples illustrating the errors of the illustrated CM positions are shown in Figure 3. The calculated CM matched exactly with the illustrated CM (0% error) in only 1 out of 33 images (book 2, front support). The image with the largest error (39%) was a single-leg bridge from book 4 (Figure 2). Calculated CM were often superior to (26 out of 33, or 78.8%) to the illustrated positions. One common misconception was that the illustrated CM tended to lie within the body in postures where the calculated CM was outside the body (e.g. half headstand, seated pike stretch, Fig. 3).

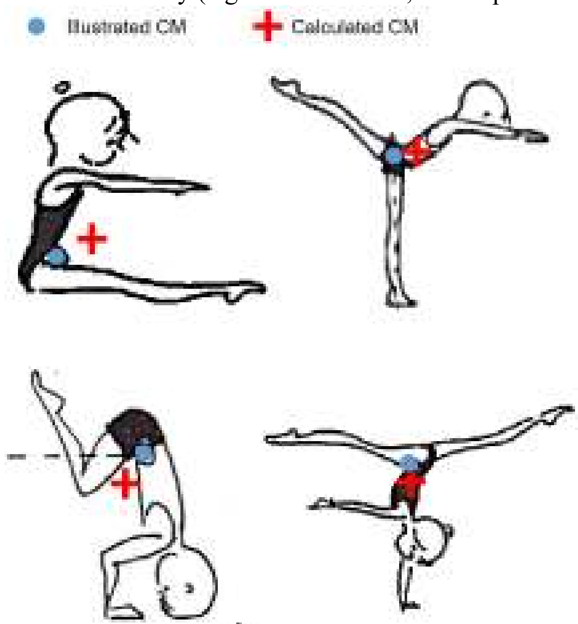

Fig. 3. Examples of error in the centre of mass (CM) positions illustrated in the gymnastics textbooks.

Table 1. Errors of Illustrated Centre of Mass (CM) Positions in Textbooks

Book	Image	Plane	Type of Balance	Error	Calculated CM Description	
					Ground reference	Anatomical reference
1	1	Sagittal	Candlestick	24.5%	Lower	Superior,
	2	Sagittal	Candlestick	19.2%	Higher	Superior,
	3	Frontal	Upright	7.1%	Lower	Inferior
	4	Sagittal	Bridge	6.6%	Higher	Superior,
2	5	Sagittal	V-Sit	5.7%	Higher	Superior,
	6	Sagittal	V-Sit	8.8%	Higher	Superior,
	7	Sagittal	Bridge	12.2%	Lower	Superior,
	8	Sagittal	Front support	0.0%	Same	Same
	9	Sagittal	Tuck	9.4%	Higher	Superior,
	10	Sagittal	Hollow hold	7.4%	Higher	Superior,
	11	Sagittal	Front split	12.3%	Higher	Superior,
	12	Frontal	Upright	1.2%	Lower	Inferior
3	13	Sagittal	Scorpion stand (ankle hold)	19.0%	Higher	Superior, posterior
	14	Sagittal	Standing pike	4.0%	Higher	Superior,
	15	Sagittal	One-handed handstand split	13.8%	Lower	Superior, anterior
	16	Sagittal	Standing (single leg	19.1%	Higher	Superior, posterior
	17	Sagittal	Handstand	7.4%	Lower	Superior,
	18	Sagittal	Half headstand	27.9%	Lower	Superior,
	19	Sagittal	Seated pike stretch	22.2%	Higher	Superior, anterior
	20	Frontal	Side scale	6.7%	Lower	Inferior
	21	Frontal	Side scale	5.3%	Higher	Superior
	22	Frontal	Side scale	4.2%	Higher	Superior
	23	Sagittal	Half headstand	27.7%	Lower	Superior,
	24	Sagittal	Arabesque	18.2%	Higher	Superior,
	25	Sagittal	Cobra pose	17.6%	Higher	Superior, posterior
	26	Frontal	Upright standing	9.0%	Lower	Inferior
4	27	Frontal	Handstand	18.4%	Higher	Inferior
	28	Frontal	Upright standing	11.8%	Lower	Inferior
	29	Sagittal	Handstand split	12.2%	Lower	Superior, posterior
	30	Sagittal	Standing (single leg raise)	7.7%	Higher	Superior, anterior
	31	Sagittal	Single-leg bridge	39.0%	Lower	Superior, posterior
	32	Sagittal	Half handstand	9.0%	Lower	Superior, anterior
	33	Sagittal	Arabesque	8.2%	Higher	Superior, posterior

* Ground reference – Calculated CM was higher/lower than illustrated CM in textbooks. Anatomical reference – Calculated CM was superior/inferior, and/or anterior/posterior to illustrated CM.

Discussion

This study aimed to examine if the CM position of static balances in gymnastics textbooks were correctly illustrated. Across the 33 balance images extracted from four gymnastics textbooks, a moderate error of

12.8% (ranging from 0 to 39.0%) in the illustrated CM position was found on average. While the majority of the images showed small to moderate errors, some postures (e.g. bridge) can have a very large error in the illustrated CM positions. Given that many PE teachers and coaches make reference to textbooks, incorrect illustration of CM positions can misguide their teaching strategies and decision making and hence negatively affect student learning.

Misconception of CM

One common error identified from the findings is that the illustrated CM tends to be situated within the physical boundary of the body near the hip area in postures where the calculated CM lies outside the body (e.g. half headstand, seated pike stretch, Figure 3). This mistake reflects the misconception of the authors and/or illustrators of the books. Many physics or biomechanics textbooks use the CM of the human body during upright standing as an example to explain the concept of CM. This is also true in the present study that all four selected gymnastics textbooks included the upright standing posture (error ranged from 1.2% to 11.8%, Table 1). Since the CM position lies near the naval area during upright standing, one may wrongly assume that the CM position remains in this spot regardless of the body postures. Thus, there is a need to strengthen the education of the concepts related to CM in PE, sport and exercise related programs and curricula for teacher and coach preparation. More examples of illustrated CM position of the human body performing different sports movements may be useful in clarifying that CM can lie outside the physical boundary of the body.

Results from the present study also showed that the calculated CM were superior (towards the head direction) to the illustrated CM in almost 80% of the images. Based on visual observation alone, it is difficult for one to judge the mass distribution of the different body segments. For example, the head, torso, and both arms account for over 60% of the total body mass while the two legs including thighs, shins and feet account for less than 40% of the total body mass. If the authors or illustrators assume that the lower body influences the CM to the same extent of the upper body (head, torso, arms combined), their estimated CM position would be inferior (towards the feet direction) to the actual position.

Practical Implications

Good understanding of the concept of CM is important for PE teachers and coaches to teach a student effectively. The position of CM in relation to the base of support forms the main principle that governs how well a student is able to achieve balance (Werner, Williams & Hall, 2012). A wide base of support would provide more stability as compared to a narrower base of support. Stability of a posture decreases as the height of the CM increases, making the task more difficult for the student to perform (Pallett, 2014). Coaches and teachers have to possess adequate knowledge to be able to approximate the CM of a body in different balance positions, so that they can assess the proficiency of the movement and to provide necessary progressions (Smith, 1982). Misguided by incorrect illustration of CM positions, teachers and coaches may potentially prescribe a gymnastic skill that is inappropriate for a student's level of proficiency and/or provide wrong feedback to the student. Awareness of the CM position in various balance postures is also pivotal for safe spotting (Gerling, 2009; Smith, 1982). According to Smith (1982), spotters should optimally aim to contact and support around or under the CM. If the spotter was to apply force away from the true CM, the resulting torque (a rotational force) generated will disrupt the stability of the system rather than offering support. This torque may potentially offset the balance of the student, leading to a fall.

In summary, there is a risk that incorrect illustrated of CM positions in reference materials can misguide teachers and coaches, hinder student learning, and compromise the safety of students. Thus, it is recommended that reference materials (textbooks, videos, task cards, apps, or other resources) should incorporate anatomical and biomechanical expertise in the preparation of figures to ensure that CM positions of different body postures are accurately reflected. Future research can also examine on how teachers and coaches appraise the balance images in reference materials and the extent to which inaccurate CM positions can affect teaching and learning.

Limitations

There are a few limitations to this study. First, the identification of body segments was manually performed based on body landmarks. Although the process was done by the same investigator throughout, there may be inconsistency associated with the clarity of the image and the style of the drawings by the illustrators. Second, the segmentation method calculates the total body's CM based on the location of individual segments. While the body segmental inertial properties from the literature on children were adopted (Jensen, 1986), the body segments may not be drawn in correct proportion by the book illustrators (e.g. arms were drawn too long, legs were drawn too short, head was drawn too big) and this will affect the resulting CM computation. Third, the calculation was done in a two-dimensional manner limiting to either the sagittal or frontal plane. To overcome these limitations, future studies can experimentally determine the CM position on human subjects using three-dimensional motion analysis and mathematical modelling technique. Subject-specific segmental parameters can also be obtained to better reflect the CM positions of individuals with different anthropometric profiles influenced by age, sex, and training background.

Conclusions

This study showed that the CM positions of static balance postures illustrated in gymnastics textbooks were not always accurate. While the errors were small to moderate for most postures, the illustrated CM position can be very wrong for some balances such as the bridge. One common error was that the illustrated CM tended to lie within the physical boundary of the body in postures where the true CM was outside the body. These incorrect CM illustrations and concepts in textbooks may misguide the pedagogical practices for PE teachers and coaches. To better reflect the true CM of gymnastics postures, future reference materials should incorporate anatomical and biomechanical expertise in the preparation of figures.

**Conflicts of interest - ** None.

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