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ORIGINAL ARTICLE

Relationship between throwing distance, shoulder joint range of motion, and upper limb muscle strength in boccia athletes: A preliminary study

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ABSTRACT

The purpose of this study was to examine the relationship between throwing distance, shoulder joint range of motion and upper limb muscle strength in boccia athletes. Participants were eight boccia athletes (cerebral palsy, cervical spinal cord injury, muscular dystrophy, spinal muscle atrophy) in whom throwing distance, ranges of motion at the shoulder joint, elbow joint and wrist joint and upper limb muscle strength were measured. Throwing distance was measured to the point where the ball landed so to remove any effect of the floor. Upper limb muscle strength was measured by isometric contraction using a handheld dynamometer. No correlation was found between throwing distance and range of motion of the shoulder joint, but correlations were found between throwing distance and strength of shoulder flexors (r = 0.76, $p < .05$), shoulder abductors (r = 0.84, $p < .01$), and elbow flexors (r = 0.77, $p < .05$). Active training to improve muscle strength around the shoulder joint, regardless of the underlying disease, was considered likely to lead to improvements in competitiveness. Due to the severe dysfunction of boccia athletes, training methods are often restricted. Verification of more effective training methods is needed while managing risks according to the physical function of the athlete and the type of disability.

Keywords: Performance analysis of sport, Paralympics, Sports performance, Physical function, Cerebral palsy, Cervical spinal cord injury.

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INTRODUCTION

Boccia is a Paralympic sport that was invented for individuals with severe cerebral palsy (CP) or similar severe limb dysfunctions. Competitors try to move 6 red and 6 blue balls to be as close as possible to the white “*jack*” ball. Boccia athletes are classified into 4 classes (BC1–4) according to physical function and disease. Athletes who have difficulty throwing the balls themselves fall into the BC3 class and participate in the competition using equipment called "*ramps*". Athletes who can roll the balls by throwing it themselves or kicking it with their feet are classified as BC1, 2, or 4. Athletes with motor dysfunction from a disease of cerebral origin, such as CP, are classified as BC1 or BC2. Athletes with severe disabilities are BC1. Athletes with limb dysfunction due to non-cerebral diseases such as cervical spinal cord injury and muscular dystrophy are classified as BC4. Boccia sports classes have a "*minimum impairment criteria*", and athletes with milder disabilities than these criteria do not fall under the BC class and are ineligible to participate in competitions that comply with international competition rules. Specifically, in the case of BC2 class athletes, as athletes in whom the main impairment is spasticity, confirmation of Grade 2 or higher spasticity using the Australian Spasticity Assessment Scale (ASAS) is required. In addition, in the BC4 class, the requirement is muscle strength (MS) in the upper limbs of 3 or less according to the Manual Muscle Test (MMT). Classifiers make a comprehensive judgement, including the degree to which dysfunction affects performance, but in principle, the criteria determine whether the level of dysfunction falls into that class. In any case, boccia is aimed at individuals with very severe disabilities, and how to improve competition performance efficiently is often unclear.

Studies on the competitive performance of boccia athletes remain scarce but include an analysis of the throwing motions in children with cerebral paralysis (Huang et al., 2014), a kinematic analysis of the relationship between throwing distance and accuracy (Reina et al., 2018) and analysis of the effect of seat angle on throwing accuracy (Tsai et al., 2014). All three studies were cross-sectional investigations with kinematic analysis. Few studies have revealed the kinds of training and practice boccia athletes need to improve performance, but a relationship clearly exists between boccia competitive performance and throwing distance (Kataoka et al., 2020). While boccia is not a competition of throwing distance, the ability to attain a long throwing distance can be considered to offer a competitive advantage. In particular, whether the individual can throw to a distance of 10 m appears to greatly affect win-loss ratios in boccia athletes. In addition, even athletes with central nervous system diseases such as CP may be less likely to have increased spasticity. Throwing distance is one indicator of boccia competitive performance, and training athletes with the aim of being able to throw farther may lead to improved performance. The purpose of this study was thus to examine the relationship between throwing distance by boccia athletes and physical function.

MATERIAL AND METHODS

Participants

The subjects were eight boccia athletes classed as BC2 or BC4. All were under-throwing players. Table 1 shows the subjects’ characteristics. The primary conditions of the subjects were CP, cervical spinal cord injury (CSCI), muscular dystrophy (MD), and spinal muscular atrophy (SMA). Each participant was an athlete of Japanese national team level and had competition history of three years or more. This study measured the throwing distance of the participants, their ranges of motion (ROMs) in the upper limb, and MS in the upper limb. None of the study participants had orthopaedic disease or pain and the purpose of this study was explained to them both orally and in writing before obtaining their written consent. The participants were informed that there would be no disadvantage to withdrawing from the study.

Table 1. Subject characteristics.

Subject	Sex	Age (years)	Disease	Boccia class
A	Male	36	CP	BC2
B	Male	33	CP	BC2
C	Male	22	CP	BC2
D	Female	45	CP	BC2
E	Male	39	CSCI	BC4
F	Male	27	CSCI	BC4
G	Male	17	MD	BC4
H	Male	32	SMA	BC4
Mean ± SD		31.4 ± 9.1		

Measures

Throwing distance

Participants used a ball prepared by the examiner. The distance to the landing point of the ball was measured to avoid effects from the floor. The subjects were instructed to throw the ball as far as possible without bounding. After the athlete threw the ball, two researchers confirmed the landing point of the ball and measured the distance to that point with a tape measure. The athletes performed 10 throws, and the maximum distance was used for the analysis.

Range of motion of the shoulder joint

ROMs for shoulder joint flexion and extension, abduction, horizontal adduction, and horizontal abduction were measured using a goniometer and recorded to the nearest 5 degrees.

Muscle strength of upper limbs

A handheld dynamometer μ-TAS F1 (Anima Co., Tokyo, Japan) was used to measure the MS of participants. Resistance was applied in the direction perpendicular to the direction of joint movement, and MS during isometric contraction was measured. The measured MS was shoulder flexion/extension, shoulder abduction, elbow flexion/extension, and wrist dorsiflexion/palmar flexion.

Analysis

SPSS version 28 was used for statistical analysis. After testing the normality of Kolmogorov-Smirnov test, the relevance of findings was verified by Pearson's correlation coefficient. The significance level was set at $p < .05$.

RESULTS

The mean throwing distance of participants was 6.0 ± 1.7 m. Table 2 shows ROMs and Table 3 shows MSs of the shoulder, elbow, and wrist joints. Although throwing distance did not correlate significantly with ROM, a significant positive correlation was found between the MSs of shoulder flexion, shoulder abduction, and elbow flexion (Table 4).

DISCUSSION

This study was conducted to examine factors functionally associated with throwing distance, which is one measure of competitive performance in boccia players. Boccia was originally conceived as a sport in which individuals with CP could participate, but quadriplegics can now also participate, including those with CSCI and MD. As a result, the diseases and disabilities of players have become more diverse in recent years. In this study, we limited the evaluations to ROM and MS to examine factors related to competitive performance from a common functional assessment, regardless of the underlying disease, whether of cerebral or non-cerebral origin. Throwing distance has been shown to be related to competitive performance in boccia players (Kataoka et al., 2020). This study therefore examined whether ROM and MS of the upper limb are related to throwing distance. The results showed no relationship between throwing distance and ROM, but a relationship between throwing distance and MS in shoulder flexion, abduction, and elbow flexion.

Table 2. Maximum throwing distance and shoulder joint ROM on the throwing side.

Subject	Throwing distance (m)	Flexion (degrees)	Extension (degrees)	Adduction (degrees)	Abduction (degrees)	Horizontal adduction (degrees)	Horizontal abduction (degrees)
A	6.3	130	30	0	95	150	0
B	8.7	135	75	0	110	140	20
C	5.6	150	75	0	130	130	20
D	3.8	125	35	0	85	135	10
E	6.9	155	115	0	140	135	100
F	7.5	125	95	0	130	150	45
G	5.4	170	90	0	130	130	30
H	3.8	140	85	0	115	135	5
Mean	6.0	141.3	75	0	116.9	138.1	28.8
SD	1.7	16.0	29.2	-	19.3	8.0	32.2

Table 3. Maximum throwing distance and MS on the throwing side.

Subject	Throwing distance (m)	Shoulder flexion (kgf)	Shoulder extension (kgf)	Shoulder abduction (kgf)	Elbow flexion (kgf)	Elbow extension (kgf)	Wrist dorsiflexion (kgf)	Wrist palmar flexion (kgf)
A	6.3	46.0	64.7	38.2	53.9	50.0	40.2	29.4
B	8.7	123.5	152.9	150.0	199.0	141.2	85.8	149.0
C	5.6	88.0	122.0	58.0	99.0	77.0	70.6	32.3
D	3.8	31.3	46.0	35.3	53.9	61.7	40.2	41.1
E	6.9	82.3	33.3	87.2	110.8	0	0	0
F	7.5	48.0	25.4	48.0	72.5	4.9	0	4.9
G	5.4	6.8	10.7	20.5	4.9	7.8	17.6	17.6
H	3.8	7.8	9.8	4.9	17.6	0	7.8	13.7
Mean	6.0	54.2	58.1	55.3	76.5	42.8	32.8	36.0
SD	1.71	41.0	52.8	45.5	61.3	50.1	32.4	47.7

Most under-throwing boccia players launch the ball at the time of ball release in a posture in which the trunk is slightly more rotated to the non-throwing side than it is perpendicular to the throwing direction. That is, the throwing upper limb is positioned slightly forward. In this case, the upper limb swinging in the throwing direction is thought to produce complex motions of shoulder joint flexion and abduction. This may be one reason for the association between shoulder joint flexion, abduction, MS, and throwing distance.

Singh et al. reported that the anterior deltoid, posterior deltoid, and pectoralis major muscles are strongly associated with ball release velocity in underhand throwing (2019). Although ball speed was not measured in this study, longer throwing distance is probably linked to higher ball release velocity. In the present results as well, although no association with the posterior deltoid or pectoralis major was seen, a strong correlation was observed with the anterior deltoid. However, the study by Singh et al. did not find a strong correlation between underhand throwing and biceps brachii Electromyography (EMG) activity. Throwing distance in this study was measured from the throwing line to the point at which the ball landed, with the players asked to throw the ball to get it as far as possible before it landed on the ground. Therefore, players tended to "*throw high*" rather than "*roll*" the ball, which was thought to require stronger elbow flexion MS. Johann (2019) reported that mean EMG activity of the biceps brachii is high with underhand throws and precedes the activity of the antagonistic triceps brachii muscle. Since this study also verified the relationship with MS in underhand throwing, MS in elbow flexion may be strongly related to throwing distance.

Table 4. Mean values of ROM and MS and r value of correlations with maximum throwing distance.

	Value	
ROM of shoulder joint (°)		
Shoulder flexion	141.3 (16.0)	r = -0.075
Shoulder extension	75.0 (29.2)	r = 0.312
Shoulder adduction	0 (0)	-
Shoulder abduction	116.9 (19.3)	r = 0.330
Shoulder horizontal adduction	138.1 (8.0)	r = 0.474
Shoulder horizontal abduction	28.8 (32.2)	r = 0.395
MS of upper limbs (kgf)		
Shoulder flexion	54.2 (41.0)	r = 0.747*
Shoulder extension	58.1 (52.8)	r = 0.508
Shoulder abduction	55.3 (45.5)	r = 0.810*
Elbow flexion	76.5 (61.3)	r = 0.763*
Elbow extension	42.8 (50.1)	r = 0.386
Wrist dorsiflexion	32.8 (32.4)	r = 0.255
Wrist palmar flexion	36.0 (47.7)	r = 0.478

Note. *$p < .05$.

However, since many boccia players have CP, the effects of spasticity must also be considered. Spasticity depends on the velocity of joint movement (Lance et al., 1980). If the elbow extensor muscle, as the antagonistic muscle for elbow flexion, shows strong spasticity, the MS of the biceps brachii muscle may not sufficiently contribute to the throw, so it is necessary to verify this together with spasticity.

In the past, strength training for individuals with CP was considered inappropriate because of the risk of exacerbating spasticity. However, since the 1990s, strength training in individuals with CP has been reported as effective for physical performance (Damiano et al., 1995, Andersson et al., 2003). The effectiveness of training in individuals with severe CP, such as boccia players, has yet to be fully clarified. Boccia players are often limited in their training methods because of severe functional disabilities. We are currently examining training effectiveness in boccia players with severe CP and are now beginning to identify effective training methods and assess their effectiveness in improving performance.

The current study revealed physical functional factors related to the throwing distance achieved by boccia players; i.e., those factors related to improvement of competitive performance. The underlying diseases in the players studied were not limited to CP. The present results suggest that, regardless of the underlying disease, active training to improve MS around the shoulder joint is associated with an increase in throwing distance, and thus with an improvement in competitive performance. The results suggest that it is necessary to verify more effective training methods while managing risks, depending on the physical function and disability type of the athlete. Doewes (2023) analysed sex differences in the biomechanics of boccia underhand throws. That study did not measure throwing distance, but instead examined the relationship with throwing accuracy, reporting that female players required greater swing angles and power. Most subjects in the present study were male, but female athletes also participated, so consideration of differences in physical function due to sex may be necessary. Cornejo (2022) also reported that upper extremity motions in the sagittal plane involve static trunk control. In our study, only ROM and MS in the upper extremities were examined for associations with throwing distance, but associations with trunk function will need to be evaluated.

The key limitation of this study was that the number of players included in the study was small, and continued validation by increasing the sample size will be important in the future. In addition, since the athletes suffer from various diseases and have a wide variety of disorders such as central nervous system disorders and muscle weakness, we limited our research to ROM and MS in the upper extremities as related functional factors. A stronger relationship may be revealed by examining the relationship between sex, trunk function, functional evaluation such as spasticity, and basic movements and ADL.

CONCLUSIONS

This study examined relationships between throwing distance, upper limb joint ROM, and MS. We found that MS of the shoulder flexors, abductors, and elbow flexors are strongly associated in the throwing distance of underhand throwers. Since throwing distance reflects the competitive performance of boccia players, the present results suggest that training to improve these MSs is important, regardless of the underlying disease.

AUTHOR CONTRIBUTIONS

Conceptualization: M. Kataoka. Data curation: M. Kataoka and K. Yahagi. Methodology: M. Kataoka and K. Yahagi. Data Analysis and interpretation of the results: M. Kataoka, K. Yahagi and H. Sugano. Project administration and supervision: M. Murakami. Writing - original draft: M. Kataoka. All authors reviewed the manuscript draft and revised it critically on intellectual content. All authors approved the final version of the manuscript to be published.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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