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Effects of Upper-Limb, Lower-Limb, and Full-Body Compression Garments on Full Body Kinematics and Free-Throw Accuracy in Basketball Players

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Abstract: Compression garments can enhance performance and promote recovery in athletes. Different body coverage with compression garments may impose distinct effects on kinematic movement mechanics and thus basketball free-throw accuracy. The objective of this study was to examine basketball free-throw shooting accuracy, consistency and the range of motion of body joints while wearing upper-, lower- and full-body compression garments. Twenty male basketball players performed five blocks of 20 basketball free-throw shooting trials in each of the following five compression garment conditions: control-pre, top, bottom, full (top + bottom) and control-post. All conditions were randomized except pre- and post-control (the first and last conditions). Range of motion of was acquired by multiple inertial measurement units. Free-throw accuracy and the coefficient of variation were also analyzed. Players wearing upper-body or full-body compression garments had significantly improved accuracy by 4.2% and 5.9%, respectively ($p < 0.05$), but this difference was not observed with shooting consistency. Smaller range of motion of head flexion and trunk lateral bending ($p < 0.05$) was found in the upper- and full-body conditions compared to the control-pre condition. These findings suggest that an improvement in shooting accuracy could be achieved by constraining the range of motion through the use of upper-body and full-body compression garments.

Keywords: range of motion; basketball shooting; proprioception

1. Introduction

Basketball is one of the most popular sports; at least 450 million people play basketball worldwide, ranging from registered elite players to amateurs [1]. Basketball skills can be categorized into offensive skills, including shooting, passing and dribbling and defensive skills, including blocking and stealing [2]. While shooting is the mean to score in the game, free-throws (or foul shots) are considered as one of the easiest movements, yet they can significantly influence the outcome of a game [3,4]. Movement mechanics and coordination are key to free-throwing performance [5,6] and may be regulated by wearing compression garments [7].

Compression garment can enhance performance and recovery in various sports [7,8]. Specifically, compression garments improve joint awareness, reduce muscle soreness and encourage blood circulation and thus, promote recovery [9]. Conversely, some studies have argued that upper-body compression garment may impose negative effects in hot environments and the claimed benefits may only be confined to perception of comfort [10,11]. Different movement tasks, selection of indicators, and the physical status of the athletes may also contribute to the variability and effectiveness of using compression garments during exercise, whereas garment design, such as type, coverage and tightness, may affect the functions of the garment [9]. The tightness of the compression garment has been hypothesized to change the interfacial pressure of the body [12]; however, there is a lack of studies exploring the influence of body coverage with different compression garments.

The benefits of compression garments could be attributed to the enhancement of proprioception to improve movement mechanics [13]. Hooper et al. [14] demonstrated the relationship between throwing velocity and accuracy, and improved proprioceptive signals in upper-body compression garments for baseball athletes. The compression on the cutaneous receptors or muscle spindle receptors not only enhanced the sensory information, but also filtered irrelevant mechanoreceptor information [15]. Depending on the task, the nervous system integrated these signals or information at multiple levels to mediate cutaneous and muscle afferent feedback, which is imperative for smooth coordination of movements [15–17].

There is insufficient evidence to support the use of compression garments (upper-body or lower-body) to enhance basketball performance. Atkins et al. [7] showed that wearing lower-body compression garments overnight produced negligible effects on the countermovement jump, repeated sprint and agility test performances, despite improvements in perceived fatigue and muscle soreness. Other evidence indicated that lower-leg compression garments were found to significantly reduce the range of abduction motion of the hip joint during a drop vertical jump, but produced minimal effects on the kinematics/kinetics of other lower extremity joints [13].

Furthermore, lower-body compression was shown to improve lower limb balance and stability in active females during a single-leg balance task [18]. Poor stability results in higher motion variability and may potentially weaken shooting accuracy [6,19,20]. How these findings affect other functional performances (e.g., basketball shooting) requires further investigation. Since compression garments produce mechanical restraints on body segments and joints, range of motion (ROM) has been one of the key parameters for the evaluation of kinematic effects during exercise in previous basketball studies [13,21].

Considering the relationship between compression garment coverage (upper-body, lower-body and combined) on the kinematics and shooting performance of basketball specific maneuvers is currently questionable, coaches and athletes are eager to understand what type of compression garment coverage could help them improve performance and consistency of performance. The objective of this study was to examine the effect of upper- and lower-body compression garment coverage (top, bottom and full) on the full body range of motion (ROM) and shooting accuracy of basketball free-throws. It was hypothesized that a certain compression garment condition would improve free-throw performance and consistency compared to the no-compression garment control group.

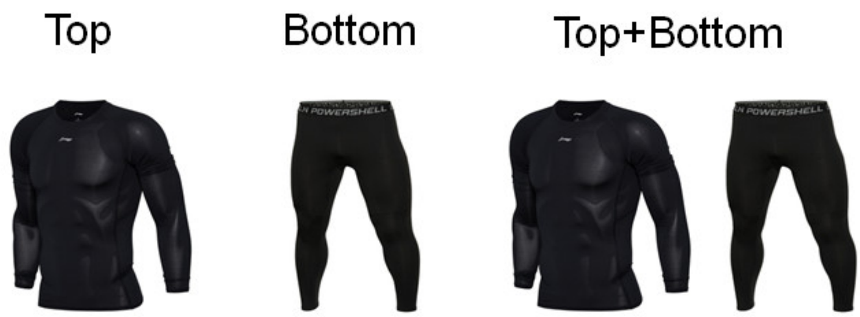
2. Materials and Methods

2.1. Participants

Twenty ($n = 20$) male basketball players were recruited from local universities. Their average age, height and body mass were 22.6 ± 1.1 years, 179.4 ± 3.4 cm and 72.7 ± 8.2 kg, respectively. All participants had at least 4 years of experiences in playing basketball and were right hand dominant single-handed shooters. The average basketball training experience and training time were 8.5 ± 2.4 years and 5.2 ± 1.6 h per week, respectively. All participants were physically fit and healthy and reported no injuries over the previous 6 months. Ethical approval (IRB-2017-BM-006) was granted from the institutional ethics committee. Written informed consent was obtained from all participants.

2.2. Experimental Conditions and Procedure

All free-throw shooting conditions were performed in our biomechanical laboratory. The free-throw distance and the height of the basketball rim were set according to the International Basketball Federation standards [19]. The participants performed single-handed free-throws under five different garment conditions, control-pre: no garment pre-control, Top: upper-body compression garment (Li Ning, Powershell, AULM043-I, Beijing, China), Bottom: lower-body compression garment bottom (Li Ning, Powershell, AUDL101-1, Beijing, China), full: both upper-body and lower-body compression garment and control-post: no garment post-control, as shown in Figure 1. Control-pre and control-post were the first and the last test conditions. The remaining three compression garment conditions (top, bottom and full) were randomly assigned as the second to the fourth conditions across participants. As the experimental protocol compared the first and last conditions, we were able to evaluate the fatigue effect [22]. For each free-throw condition, 20 free-throw shooting trials were performed. Testing of the next condition started immediately after the participant changed their garments.



(**a**) (**b**) (**c**)

Figure 1. Compression garment conditions: (**a**) top; (**b**) bottom; (**c**) full (top + bottom).

The control conditions (control-pre and control-post) were self-selected comfortable sportswear that were not compression garments. The experimenters measured the height, waist and chest circumference of the participants to determine the appropriate garment [23]. The appropriate compression garment size was pre-determined by the manufacturer's sizing guidelines and was based on the body height and mass of each participant. Next, we assigned participants compression garments one size smaller than the pre-determined appropriate size in order to increase the interfacial pressure, as recommended by the experimental protocol detailed by Williams and colleagues [12].

A motion capturing system with multiple inertial measurement units (MyoMOTION, Noraxon, Inc., Scottsdale, AZ, USA) was used to measure full-body kinematics during the free-throw shooting trials. The inertial measurement units (IMU) were attached and strapped to each body segment according to the instrument guidelines. During each free-throw trial, the participants performed shooting from the same position behind the free-throw line. The sampling frequency of the IMU was 200 Hz. The kinematic data during the free-throw motion were post-processed using Matlab software (MathWorks, Inc., Natick, MA, USA) using a 6 Hz cutoff 4th order Butterworth low-pass filter.

2.3. Outcome Measures

Outcome measures including performance score (accuracy) and joint ROM variables were investigated. The performance score was gauged using an ordinal six-point (0 to 5 point) scoring system. Five, four and three points denoted a clean score, that the ball hit the rim and went in, and that the ball hit the backboard and went in, respectively. Two, one and zero points denoted that the ball hit the rim and missed, hit the backboard and missed and missed complete, respectively, as illustrated in Table 1 [19,24]. The consistency of the score was also assessed by the coefficient of variation (i.e., the ratio of the standard deviation to the mean of the trials).

Table 1. The six-point basketball shooting performance score system.

Performance	**Scored**			**Missed**		
	Clean (Swish)	**Rim & In**	**Backboard & In**	**Rim & Out**	**Backboard & Out**	**Complete Miss**
Score	5	4	3	2	1	0

ROM of the head, trunk, elbow, shoulder, wrist, hip, knee and ankle joints in the sagittal, coronal and frontal planes were calculated. Data were averaged across trials for each participant in each condition which served as the targeted average profile for subsequent statistical analysis [25]. We did not view the within-participant effect (trial) of ROM as an independent observation or random factor to be analyzed.

2.4. Data Analysis

All statistical analysis was performed in SPSS 21 (IBM, New York, NY, USA). Prior to statistical analysis, the Shapiro–Wilk test was performed to check for the normality of the kinematic data, and it was satisfied. The Wilcoxon signed-rank test was performed to compare free-throw performance scores between the control-pre- and control-post-control conditions to ensure that there was no learning or fatigue effect (i.e., Control pre- and post-control were not significantly different). Furthermore, one-way repeated measures analysis of variance (ANOVA) was performed to examine any significant difference for joint ROM variables between the control-pre, top, bottom and full conditions, followed by the post hoc pairwise comparison of Least Significant Difference (LSD) if a significant main effect was found. We chose the LSD approach as our research hypothesis was more focused on planned comparisons. As such, we regarded the ANOVA as an additional constraint [26]. Similarly, the comparison for the performance score and the coefficient of variation was performed using a nonparametric test (Friedman test), with the post hoc pairwise Wilcoxon signed-rank test, as the performance score was gauged in an ordinal scale. Level of significance was set at $p = 0.05$. The indices of effect size for the ANOVA and post hoc pairwise comparison were partial η^2 and Cohen's d, respectively.

3. Results

3.1. Control-Pre and Control-Post Conditions

There was no significant difference in performance score between the control-pre (Median = 2.975) and control-post (Median = 3.075) conditions ($Z = -1.430$, $p = 0.153$). Similarly, there was no significant difference in the coefficient of variation of performance score between the control-pre and control-post conditions ($Z = -1.382$, $p = 0.167$). We assumed that there was no pronounced carry-over or fatigue effect that significantly affected performance over the course of the experiment.

3.2. Free-Throw Accuracy

There were no significant differences in free-throw performance score ($\chi^2(4) = 6.510$, $p = 0.089$) or the coefficient of variation of the performance score ($\chi^2(4) = 5.629$, $p = 0.131$) between the conditions (control-pre, top, bottom or full). However, post hoc pairwise comparison showed that the free-throw performance scores of the top (Median = 3.1, $Z = -2.357$, $p = 0.018$) and full (Median = 3.15, $Z = -2.112$, $p = 0.035$) conditions were significantly larger than that of the control-pre condition (Median = 2.975), as shown in Tables 2 and 3.

Table 2. Descriptive statistics of the averaged and coefficient of variation of the free-throw performance score.

Condition	Performance Score		Coefficient of Variation (%) Mean (Standard Deviation)
	Median	Mean (Standard Deviation)	
Control-Pre	2.975	2.975 (0.419)	38.04 (6.67)
Top	3.100 *	3.168 (0.382)	36.78 (7.05)
Bottom	3.050	3.035 (0.411)	37.06 (7.07)
Full	3.150 *	3.175 (0.385)	36.19 (7.58)
Control-Post	3.075	3.123 (0.476)	35.88 (8.61)

* significant difference ($p < 0.05$) compared to the control-pre condition by post hoc Wilcoxon signed-rank test.

Table 3. Probability values (*p*-value) of the average (upper right triangle) and coefficient of variation (lower left triangle) of the free-throw performance score.

Coefficient of Variation	Performance Score			
	Control-Pre	Top	Bottom	Full
Control-Pre		0.018 *	0.230	0.035 *
Top	0.296		0.152	0.888
Bottom	0.227	0.654		0.159
Full	0.107	0.794	0.344	

* significant difference ($p < 0.05$) by post hoc Wilcoxon signed-rank test.

3.3. Full-Body Joint Range of Motion (RoM)

One-way ANOVA repeated measures showed that the variation in compression garments imposed significant effects on the ROM of head flexion ($p = 0.014$, partial $\eta^2 = 0.169$), trunk lateral bending ($p = 0.024$, partial $\eta^2 = 0.152$), left shoulder flexion ($p = 0.041$, partial $\eta^2 = 0.152$), right shoulder rotation ($p = 0.048$, partial $\eta^2 = 0.128$) and left knee flexion ($p = 0.003$, partial $\eta^2 = 0.212$). Post hoc pairwise comparison showed that the top condition significantly reduced the head flexion ($p = 0.037$; d = 0.503; 1.346, 95% CI 0.376 to 2.315) and trunk lateral bending ($p = 0.042$; d = 0.487; 1.039, 95% CI 0.041 to 2.036) ROM compared with the control-pre condition (Table 4). Similarly, the full condition significantly reduced head flexion ($p = 0.009$; d = 0.650; 1.346, 95% CI 0.376 to 2.315) and trunk lateral bending ($p = 0.028$; d = 0.532; 1.446, 95% CI 0.173 to 2.718) ROM compared to the control-pre condition.

Table 4. Descriptive statistics and one-way ANOVA repeated measures outcome of the range of motion of head and trunk in different compression garment conditions.

	Range of Motion, Mean (Standard Deviation)				ANOVA Repeated Measure	
	Control-Pre	Top	Bottom	Full	Effect Size	*p*-Value
Head FL/EX	10.57 (3.81)	9.53 (3.1) ^{a}	9.75 (3.37)	9.22 (3.07) ^{A}	0.169	0.014 *
Head lateral bending	6.14 (2.83)	5.80 (2.69)	6.05 (2.99)	5.87 (2.62)	0.019 ^{g}	0.694
Head axial rotation	13.17 (8.04)	17.11 (12.74)	15.02 (10.49)	14.42 (8.63)	0.053	0.368
Trunk FL/EX	19.20 (6.24)	17.15 (5.96)	18.43 (5.85)	18.15 (6.42)	0.11	0.082
Trunk lateral bending	10.21 (4.24)	9.17 (4.38) ^{a}	9.88 (3.63)	8.77 (4.01) ^{a}	0.152	0.024 *
Trunk axial rotation	11.05 (4.56)	11.46 (5.04)	10.99 (4.36)	11.39 (4.37)	0.018 ^{g}	0.687

FL/EX: flexion/extension; * significant difference ($p < 0.05$) using one-way ANOVA repeated measures; ^{g} Greenhouse–Geisser correction to adjust the lack of sphericity; ^{a} and ^{A} denote $p < 0.05$ and $p < 0.0125$ than the control-pre condition.

Compared to that of the bottom condition, both the top ($p = 0.01$; d = 0.642; 3.422, 95% CI 0.929 to 5.915) and full ($p = 0.003$; d = 0.778; 3.530, 95% CI 1.405 to 5.655) conditions significantly reduced the ROM of the left shoulder flexion, while the top condition had significantly larger right shoulder rotation compared with the control-pre ($p = 0.013$; d = 0.611; 38.316, 95% CI −8.98 to 67.65) and bottom ($p = 0.041$; d = 0.491; 23.028, 95% CI 1.08 to 44.976) conditions (Table 5). The control-pre condition had significantly larger left knee flexion ROM than the bottom ($p = 0.026$; d = 0.539; 2.605, 95% CI 0.345 to 4.864) and full ($p = 0.002$; d = 0.804; 2.908, 95% CI 1.214 to 4.602) conditions. Similarly, the top condition had a significantly larger left knee flexion ROM than the bottom ($p = 0.044$; d = 0.482; 2.047, 95% CI 0.059 to 4.035) and full ($p = 0.018$; d = 0.585; 2.351, 95% CI, 0.469 to 4.232) conditions (Table 6).

Table 5. Descriptive statistics and one-way ANOVA repeated measures outcome of the range of motion of the upper limb in different compression garment conditions.

	Range of Motion, Mean (Standard Deviation)				ANOVA Repeated Measure	
	Control-Pre	**Top**	**Bottom**	**Full**	**Effect Size**	***p*-Value**
L elbow FL/EX	49.35 (23.12)	51.38 (23.28)	50.95 (22.82)	51.24 (24.05)	0.048	0.417
R elbow FL/EX	93.30 (13.27)	89.43 (12.46)	89.14 (13.79)	89.82 (14.38)	0.098	0.116
L shoulder FL/EX	30.06 (12.77)	26.98 (11.58)	30.40 (12.66) ^{B}	26.87 (10.48) ^{C}	0.152 ^{g}	0.041 *
R shoulder FL/EX	44.11 (18.88)	40.48 (16.96)	44.01 (19.11)	41.47 (17.2)	0.148 ^{g}	0.148
L shoulder AB/AD	124.84 (113.81)	125.37 (132.49)	133.85 (120.05)	132.36 (124.17)	0.022 ^{g}	0.66
R shoulder AB/AD	72.93 (51)	75.01 (55.07)	76.05 (48.47)	78.02 (71.69)	0.012 ^{g}	0.821
L shoulder rotation	50.50 (40.81)	58.41 (51.4)	67.74 (83.18)	59.95 (61.04)	0.089 ^{g}	0.176
R shoulder rotation	90.38 (45.46)	128.70 (81.71) ^{a}	105.67 (67.28) ^{b}	118.07 (73.94)	0.128	0.048 *
L wrist RA/UL	35.80 (26.08)	34.93 (27)	35.12 (28.48)	38.26 (32.93)	0.036	0.552
R wrist RA/UL	70.79 (27.55)	79.36 (29.02)	71.34 (33.37)	77.37 (31.8)	0.071 ^{g}	0.249
L wrist FL/EX	39.21 (33.56)	39.37 (41.11)	42.20 (43.93)	42.90 (45.34)	0.011 ^{g}	0.885
R wrist FL/EX	105.39 (34.39)	109.35 (36.59)	110.83 (35.36)	106.85 (35.66)	0.026	0.675
L palm rotation	49.54 (47.21)	51.35 (48.84)	60.70 (72.13)	52.23 (55.49)	0.067 ^{g}	0.269
R palm rotation	93.97 (46)	126.74 (77.75)	113.01 (81.54)	110.93 (66.53)	0.117	0.066

FL/EX: flexion/extension; AB/AD: abduction/adduction; RA/UL: Radial/Ulnar deviation; * significant difference ($p < 0.05$) using one-way ANOVA repeated measures; ^{g} Greenhouse–Geisser correction to adjust the lack of sphericity; ^{a} denotes $p < 0.05$ than the control-pre condition; ^{b} and ^{B} denote $p < 0.05$ and $p < 0.0125$ than the top condition; ^{C} denotes $p < 0.0125$ than the bottom condition.

Table 6. Descriptive statistics and one-way ANOVA repeated measures outcome of the range of motion of the lower limb in different compression garment conditions.

	Range of Motion, Mean (Standard Deviation)				ANOVA Repeated Measure	
	Control-Pre	**Top**	**Bottom**	**Full**	**Effect Size**	***p*-Value**
L hip FL/EX	23.56 (6.8)	22.58 (6.65)	22.34 (7.8)	21.81 (7.19)	0.076 ^{g}	0.22
R hip FL/EX	26.47 (4.49)	25.14 (6.02)	26.19 (6.26)	25.93 (5.85)	0.065	0.274
L hip AB/AD	5.69 (1.73)	6.46 (2.38)	5.57 (1.64)	6.28 (2.36)	0.069	0.251
R hip AB/AD	6.95 (2.6)	7.22 (2.72)	6.31 (2.42)	6.97 (2.62)	0.069	0.248
L hip rotation	9.99 (3.57)	10.03 (3.52)	9.31 (3.04)	9.45 (2.53)	0.043 ^{g}	0.445
R hip rotation	12.62 (3.89)	12.83 (4.19)	12.43 (4.17)	12.30 (4.61)	0.013	0.861
L knee FL/EX	51.86 (8.63)	51.30 (8.15)	49.25 (10.08) $^{a, b}$	48.95 (9.37) $^{A, b}$	0.212	0.003 *
R knee FL/EX	53.77 (7.33)	52.90 (7.88)	53.61 (6.61)	52.94 (6.67)	0.036	0.549
L knee rotation	10.64 (4.39)	11.35 (5.59)	10.26 (3.99)	10.35 (4.21)	0.051 ^{g}	0.37
R knee rotation	14.96 (4.52)	14.72 (6.12)	15.68 (5.86)	15.43 (5.01)	0.031	0.61
L knee AB/AD	7.15 (4.52)	7.92 (4.46)	6.81 (2.89)	7.00 (3.28)	0.029 ^{g}	0.587
R knee AB/AD	8.32 (3.72)	7.67 (3.84)	9.10 (4.32)	8.48 (3.58)	0.048	0.418
L ankle PL/DO	61.22 (16.82)	64.36 (8.64)	61.71 (8.01)	61.83 (9.08)	0.049 ^{g}	0.362
R ankle PL/DO	60.93 (11.16)	61.97 (6.1)	60.76 (7.49)	61.82 (8.21)	0.019 ^{g}	0.682
L ankle EV/IV	25.31 (14.66)	22.84 (13.08)	24.29 (11.37)	23.38 (12.54)	0.041	0.49
R ankle EV/IV	26.49 (13.19)	23.04 (11.28)	22.95 (8.38)	21.27 (10.34)	0.123	0.056
L ankle AB/AD	15.28 (4.08)	15.47 (4.5)	15.52 (4.76)	16.12 (5.18)	0.016 ^{g}	0.732
R ankle AB/AD	13.98 (3.73)	14.69 (4.46)	15.17 (4.9)	14.43 (4.14)	0.077	0.204

FL/EX: flexion/extension; AB/AD: abduction/adduction; EV/IV: eversion/inversion; PL/DO: plantarflexion/dorsiflexion; * significant difference ($p < 0.05$) using one-way ANOVA repeated measures; ^{g} Greenhouse–Geisser correction to adjust the lack of sphericity; ^{a} and ^{A} denote $p < 0.05$ and $p < 0.0125$ than the control-pre condition; ^{b} denotes $p < 0.05$ than the top condition.

4. Discussion

This study examined the effect of upper and lower-body compression garments on the body kinematics and shooting accuracy of basketball free-throws. Our study found that upper-body (top) or full-body (top + bottom) compression garments significantly improved the performance of basketball free-throws; however, there was no significant improvement in the consistency of performance. Overall, mechanically, compression garments had a significant influence on the ROM of the head flexion, trunk lateral bending, left (non-dominant side) shoulder flexion, right (dominant side) shoulder rotation and left knee flexion as indicated by the ANOVA findings. Post hoc comparisons showed that wearing either upper- or full-body garments constrained the ROM of head flexion and trunk lateral bending which could be associated with improved trunk stability and thus, improved performance [27]. The relationship between the condition of the head movement and stability and free-throw accuracy was advocated previously, but not well understood [28]. On the other hand, garment coverage of the lower body (bottom or full-body gear) significantly reduced the ROM of the left (non-dominant) side knee joint in the sagittal plane, but not the right (dominant) side, because experienced players tended to adjust the knee joint of the dominant side to greater extent for better performance [29]. Theoretically, compression of the knee joint enhanced proprioception and thus performance [30,31] notwithstanding that our study did not demonstrate an improved shooting score for lower-body (bottom) garments. In addition, the reduced head flexion and trunk lateral bending ROM could implicate successful shooting performance.

Elbow and wrist movements are determinants of free-throw performance and player skill levels [20]. Skilled players coordinate the shooting arm by constantly compromising between elbow and wrist movements to adapt to subtle changes in release parameters of the ball (e.g., release height, angle of ball projection, velocity at ball release) [20]. In addition, more highly skilled players tend to maximize the ROM of the wrist joint [20]. top compression garments help to constrain the ROM of the elbow, and thus players can focus on optimizing distal joint (wrist) motion only [20]. In our study, although there were no significant main effects on the ROM of the elbow and wrist joints, pairwise comparisons showed that upper-body (top) garments significantly reduced the ROM of the right (dominant) side elbow, but increased that of the wrist radial/ulnar deviation and palmar rotation compared to that of the control-pre condition. This was likely due to the fact that the uncovered wrist joint compensated the reduced motion of the elbow [20]. In fact, some statisticians argued that conducting and interpreting post hoc analyses could still be valid even though the main effect was not significant [32,33].

The enhanced proprioception by compression garments may also facilitate the organization of compensatory behavior between joints for better performance. This was supported by existing studies that the proprioception (joint position sense) of the elbow and wrist joints was correlated with the success rate of the free-throw tasks [34]. More highly skilled players managed to optimize their performance based on the perceptual consequence of their actions [35].

A previous study suggested that the shoulder joint plays an important role in the action of basketball free-throws. Kaya et al. [36] found that free-throw performance was significantly correlated with the peak torque of the shoulder joint muscles and the shoulder joint position sense at 160° in the dominant side. While we anticipated that compression garments would amplify the proprioception [30], enhance stability and reduce the ROM of the shooting limb (right side), our study found that the ROM of the upper-body was significantly smaller when wearing top compression garments than when wearing bottom garments. Although there were no significant differences compared to that of the control-pre condition, we believe that the increased trend of the joint ROM may indicate that wearing lower-body (bottom) garments alone had a negative effect on the shoulder joint. From the kinetic chain perspective, intervention at the lower limb level may alter energy generation which can be transferred to the upper limbs and thus considerably influences upper limb movement tasks (e.g., racket and ball speed in racket sports) [19,37]. The influence of lower limb garments on the upper limbs may also be the reason that the full-body garments did not have an effect on the elbow and wrist joints, despite upper-body garments having an effect.

There were some limitations in this study. First, although we demonstrated no carry-over effect as revealed by the fact that there was no significant difference between the performance score of the control-pre and control-post conditions, there was an improvement trend on both the performance score and consistency. We believed that the randomized order assigned on the garment condition could minimize the carry-over effect. Second, our short adaptation time for each compression garment condition may not be adequate enough, despite that there is no consensus on the duration of adaptation in the past studies. Future studies may consider tests with longer adaptation in different days or weeks or considering the variation of kinematic variables [38]. Third, we presented only joint ROM in this study. More comprehensive analysis with discrete variables (peak angle, angular velocity), joint power, muscle force, proprioception as well as stability should be considered to evaluate their influence and underlying mechanism on the free-throw shooting performance. Asymmetry sport activity (e.g., single-handed shooting) may produce unique sequential coordination of the upper and lower limb with coherent patterns of muscle activation [39]. Forth, our study confined to non-professional basketball players. Playing level and sex effects may contribute to variations in movement strategy, skeletal alignment and muscle strength and could also be investigated. Lastly, the compression garments may impose different levels of pressure on the participants depending on their body built. Future study shall consider measuring the compression level in each condition.

5. Conclusions

Players wearing upper-body or full-body compression garment significantly improved basketball free-throw accuracy by 4.2% and 5.9%, respectively, but not on the intertrial consistency. full body kinematics data suggested that the improved performance could be attributed to the reduced ROM of head flexion and lateral bending of the trunk. Future studies investigating the relationship between shooting performance in basketball, reduced ROM and enhanced proprioception or stability are required.

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