Analysis of Joint Correlation between Arm and Lower Body in Dart Throwing Motion

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***Abstract*—As the population continues to age, the number of elderly people requiring healthcare is increasing. In order to improve their physical function, they need to get physical training. There are activities which require integrated arm movements and lower body movements. However there are no quantitative testing methods of the degree of recovery for the coordination between arm movements and lower body movements. In this study, we focus on dart throwing motion as arm movements in lower body movements and suggest the quantitative evaluation of the coordination between arm movements and lower body movements in dart throwing motion. Normalized correlation coefficient (NCC) between arm and lower body was computed at different throwing distances. In addition the standard deviation of the NCC was computed in order to investigate the stability of the joint correlation evaluation. This analysis shows that the correlation between elbow and ankle, or between elbow and knee, are increased at throwing long distance. We suggest that the NCC between elbow angle and right knee angle may be used for the evaluation of the joint correlation between arm movements and lower body movements in dart throwing motion.**

***Index Terms*—Motion Analysis, Joint Correlation, Dart Throwing**

I. Introduction

In this paper, we propose the quantitative evaluation of the integration of arm movements and lower body movements.

Recently, the life expectancy in developed regions has increased, increasing the proportion of elderly people in the population. This situation has caused an economic problem of rising health care costs for elderly people [1]. In order to solve this problem, it is important to maintain and improve physical function of elderly people. For maintaining and improving physical function, physical training is essential.

Specifically, fall-related injuries represent a major threat to physical function and quality of life for elderly people [2]. In addition, falls are a serious public health problem because it is the leading cause of death from injury among elderly people [3]. Thus, effective training is important in order to improve balance and prevent falls.

Recent interest in physical training has focused on the integration of arm movements and lower body movements. Originally, physical training for arm movements and lower body movements were conducted separately [4]. For instance, arm trainings have been conducted in a seated position [5]. Similarly, training for lower body in a standing position seldom includes training for functional arm movements in reaching, grasping or other manipulatory tasks [6]. However, in recent research, training for the lower body is suggested to be important for the full effective recovery of arm [7]. In addition, Carr et al. suggested that training arm and lower body in isolation is inadequate for recovery of physical function. For example, activities such as cooking, bathing and dressing require integrated lower body movement and arm movement, such as reaching, grasping, and manipulation of objects in a standing position [8]. Waller et al. argued that throwing motion of arm, involving grasp, reach and release of the object, in a standing position improves the ability of lower body movements [4]. Likewise, Meusel recommended training with throwing a small ball in order to improve coordinative skills [9]. Thus, training with throwing motion is effective for recovery of physical function.

However it is unclear how people should perform throwing motion in order to achieve the most effective recovery of integrated arm and lower body movements. For example, it is not known which throwing distance is the most effective in order to improve their physical function.

In previous studies for coordinative training, there are only testing methods for the degree of recovery of arm movements or lower body movements in isolation. Thus, in order to evaluate the recovery process for coordinative ability, quantitative methods are necessary to test integrated arm and lower body movements.

In this study, we develop a quantitative evaluation of the integration of arm and lower body movements during a dart-throwing task. Besides, we investigate the dart-throwing motion at different throwing distances.

II. Analysis Methods

A. Condition of Dart Throwing Motion

It has been argued that a good javelin thrower transfer forces between lower body and upper body during the delivery, using coordinated motion of the body segments [10]. In throwing motion at long distance, it is important to coordinate and correlate lower body segments and upper body segments and

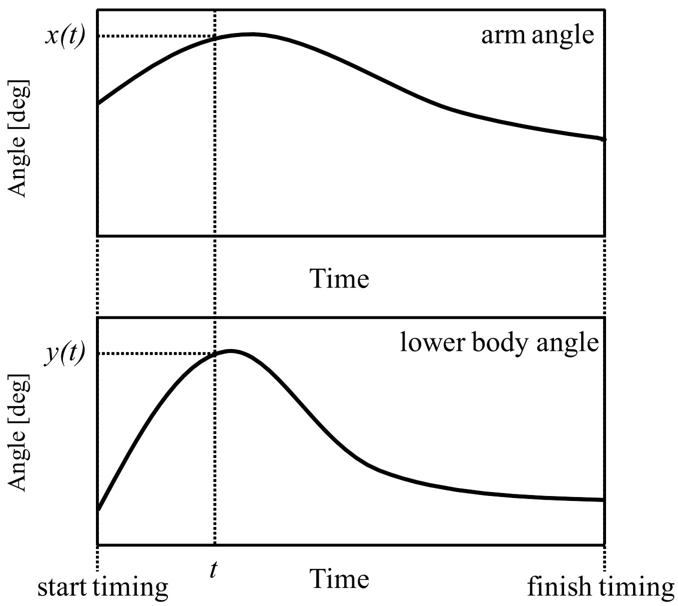


Fig. 1. Example of Coordination Evaluation with NCC.

transfer forces between lower body and upper body. Similarly, in basketball shooting motion at longer shooting distances, Robins et al. reported a significant reduction in the variability of joint correlations between arm joints [11]. In order to achieve a specific movement, for example shooting motions at long distance, a very similar movement pattern is required.

Therefore we hypothesized that joint correlation would increase for throws of longer distances.

According to the rules of the World Darts Federation, the throwing distance to the dart board is set to 2.44m in normal darts game [12]. In this study, participants throw at distances of 1.2m (D1), 2.4m (D2), 3.6m (D3), 4.8m (D4), and 6.0m (D5). The throwing distances D3, D4 and D5 are defined as longer distances compared to the distance of normal darts game. On the other hand, the throwing distances D1 and D2 are defined as shorter distances.

B. Joint Correlation between Arm and Lower Body

In order to achieve complex voluntary movements, the correlation between joints is important. The correlation between the joints transfers forces and movements toward every joint during voluntary movements [13]. In particular, a fast movement of a joint is achieved by coordinative movements in other joints [14]. In a previous study, it is suggested that the correlation between two joints is required during a normal or complex voluntary movements, running [15], triple jumping [16], javelin throwing [17], and basketball shooting [17].

In this study, it is important to investigate the correlation between arm joint and lower body joint during dart throwing motion in order to evaluate the degree of the joint correlation. In previous study, in order to quantify the joint correlation, correlation coefficient between joints is calculated in human voluntary movements [18][19]. Thus, normalized correlation coefficient (NCC) between arm joint and lower body joint was applied to dart throwing motion in this study.

C. Joint Correlation Analysis

In order to investigate coordinated movements in dart throwing motion, correlation between arm data and lower body data is studied. In this study, arm and lower body data is sequence during throwing dart motion as shown in Fig. 1

In order to understand how arm movements and lower body movements are coordinated to achieve dart throwing motion, NCC $R_k(x,y)$ between arm data and lower body data at the k-th trial were calculated as in eqs. (1)–(3). As arm data ($x(t)$), right shoulder joint angle, right elbow joint angle and right wrist joint angle were used. As lower body data ($y(t)$), right-and-left hip joint angle, right-and-left knee joint angle, and right-and-left ankle joint angle were used. The joint angle indicates joint extension-flexion.

If the absolute value of computed NCC between certain arm data and certain lower body data is high at a particular throwing distance, it is defined that the degree of the correlation between them is high at this throwing distance. For instance, NCC between certain arm data and certain lower body data is close to 1 or -1 at certain throwing distance, it indicates that these two data move in a correlated manner. On the other hand, NCC between certain arm data and certain lower body data is close to 0 at certain throwing distance, it indicates that these two data move independently at this throwing distance. In eqs. (1)–(3), $\bar{x}$ indicates arithmetic average of $x(t)$ and $\bar{y}$ indicates arithmetic average of $y(t)$.

$$R_k(x,y) = \frac{\sum_{t=1}^{T_{total}} f(t)g(t)}{\sqrt{\sum_{t=1}^{T_{total}} f(t)^2}\sqrt{\sum_{t=1}^{T_{total}} g(t)^2}} \quad (1)$$

$$f(t) = x(t) - \bar{x} \quad (2)$$

$$g(t) = y(t) - \bar{y} \quad (3)$$

The definition of dart throwing motion is as follows.

- The start time
  The first time at which the elbow joint angular velocity rises above zero.
- The finish time
  The first time at which the elbow joint angular velocity reduces to zero after the start time.

In addition, standard deviation of NCC (SCC) $SD(x,y)$ for all N trials at each throwing distance is calculated in order to investigate the stability of the evaluation with NCC as in eq. (4). If computed SCC between certain two data is low in relation to SCC between other two data, the evaluation is defined as the effective evaluation for the joint correlation between arm and lower body.

$$SD(x,y) = \sqrt{\frac{\sum_{k=1}^{N}(R_k(x,y) - \overline{R}(x,y))^2}{N-1}} \quad (4)$$

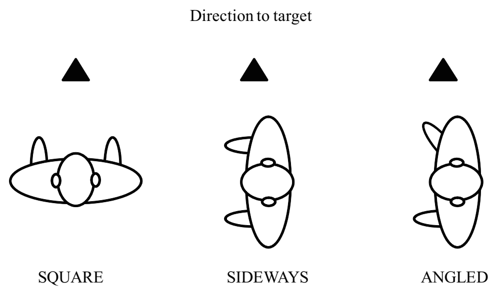


Fig. 2. Three Stance of Feet in Throwing Darts Motion.

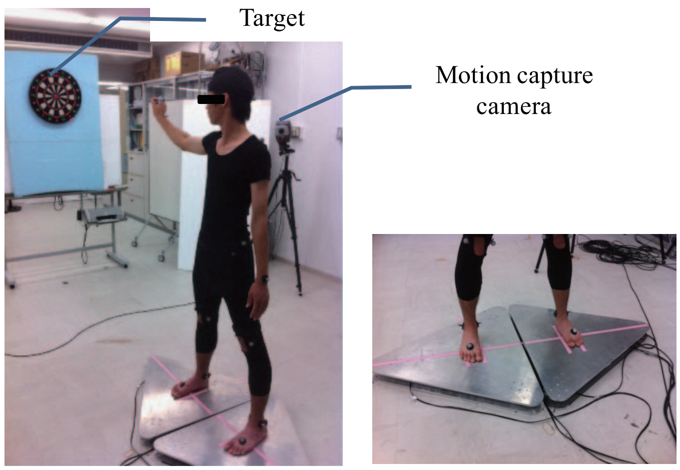


Fig. 3. Posture of Participants.

D. Data Processing Method

Joint angles were calculated using measurements of motion-tracking point positions. j-th joint angles ($\theta_j(t)$) at the certain time t was calculated as in eq. (5). The numerator of this equation consists of a inner product of a vector ($\mathbf{v}_{j,i}(t)$) from joint j to joint i and a vector ($\mathbf{v}_{j,k}(t)$) from joint j to joint k. The denominator of this equation consists of a product of a absolute value of $\mathbf{v}_{j,i}(t)$ ($|\mathbf{v}_{j,i}(t)|$) and a absolute value of $\mathbf{v}_{j,k}(t)$ ($|\mathbf{v}_{j,k}(t)|$).

$$\theta_j = \arccos\left(\frac{\mathbf{v}_{j,i}(t) \cdot \mathbf{v}_{j,k}(t)}{|\mathbf{v}_{j,i}(t)||\mathbf{v}_{j,k}(t)|}\right) \tag{5}$$

E. Statistical Analysis

A one-way within throwing distances repeated analysis of variance (ANOVA) was performed to assess the degrees of the correlation between arm data and lower body data with post hoc two-sided Tukey's tests when appropriate. In order to evaluate statistical significance, significance level was set to $p < 0.05$ for the analyses.

III. Experimental Setup

A. Experiment Overview

In order to analyze a dart throwing motion, biological data from participants was measured during the experiment. Body motion trajectory was recorded. In addition, there are mainly three stances in throwing darts motion, which are square stance, sideways stance and angled stance as shown in Fig. 2 [20]. In this study, participants have sideways stance, with both legs turned in a vertical direction to the target and shoulder-width apart as shown in Fig. 3.

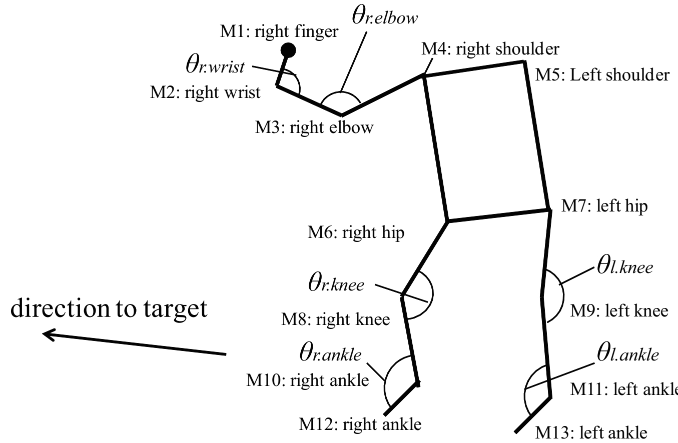


Fig. 4. Definition of Position-Markers and Joint Angles.

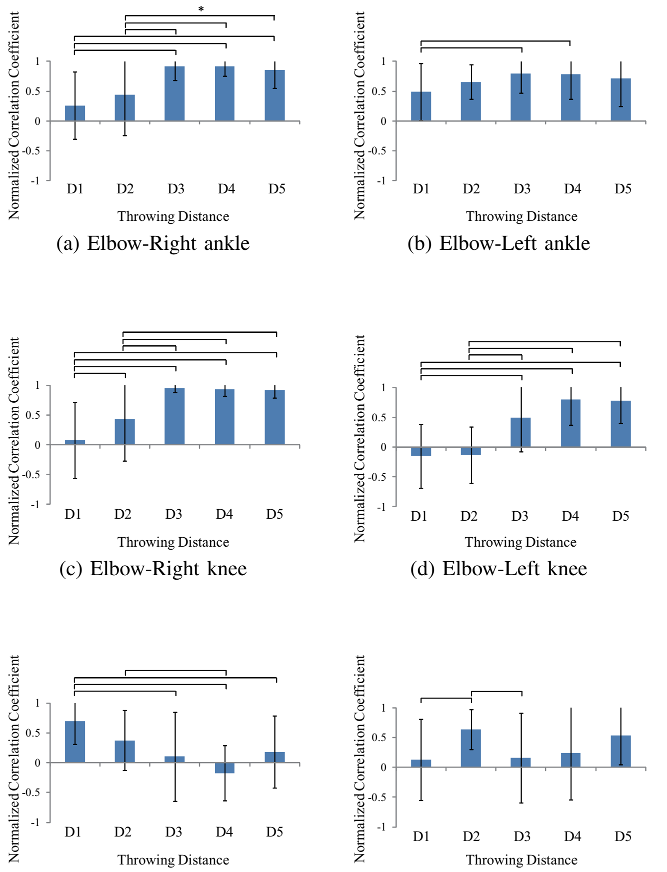
B. Participants

Total of three young people participated in our experiment. They were healthy right handed male (age: 22.0 $\pm$ 1.0years old, height: 1.70 $\pm$ 0.03m, weight: 62.0 $\pm$ 5.0kg). They did not have much experience of playing dart. They performed 10 dart throws at each throwing distance. Each participant threw darts to aim at the center of the dartboard. Consent was obtained from all three participants before the experiment started, in compliance with the ethical committee of the Graduate School of Medicine and Faculty of Medicine, The University of Tokyo.

C. Data Measurement

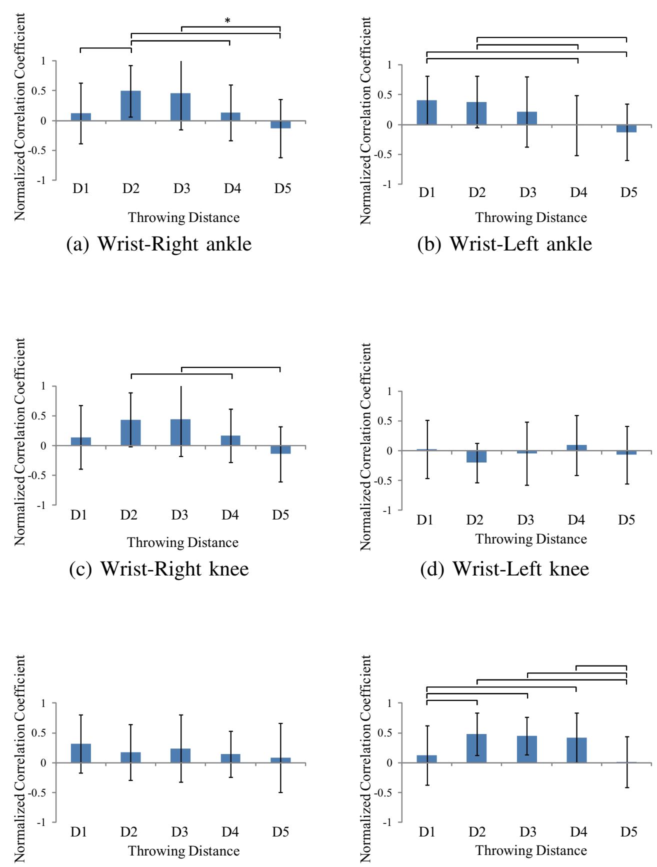
In order to measure dart throwing motion, MAC3D System (HMK-200RT; Motion Analysis Corp.) was used. In this experiment, eight cameras were used for body trajectory measurement, and a calibration for accuracy confirmation was performed before the start of recording (less than 1.0 mm). Based on the rules of the World Darts Federation, the height of the center of the dart board was set to 1.73m [12]. 13 points of body position, right finger (M1), right wrist (M2), right elbow (M3), right shoulder (M4), left shoulder (M5), right hip (M6), left hip (M7), right knee (M8), left knee (M9), right ankle (M10), left ankle (M11), right toe (M12), and left toe (M13), were measured in this study. The sampling rate for this data was 200 Hz and nine joint angles, $\theta_{r.shoulder}$, $\theta_{r.elbow}$, $\theta_{r.wrist}$, $\theta_{r.hip}$, $\theta_{l.hip}$, $\theta_{r.knee}$, $\theta_{l.knee}$, $\theta_{r.ankle}$, and $\theta_{l.ankle}$ were computed as shown in Fig. 4.

Right shoulder joint angle ($\theta_{r.shoulder}(t)$) was calculated with $\mathbf{v}_{M4,M3}(t)$ and $\mathbf{v}_{M4,M5}(t)$. Right elbow joint angle ($\theta_{r.elbow}(t)$) was calculated with $\mathbf{v}_{M3,M2}(t)$ and $\mathbf{v}_{M3,M4}(t)$. Right wrist joint angle ($\theta_{r.wrist}(t)$ was calculated with $\mathbf{v}_{M2,M1}(t)$ and $\mathbf{v}_{M2,M3}(t)$.



(a) Elbow-Right ankle (b) Elbow-Left ankle (c) Elbow-Right knee (d) Elbow-Left knee (e) Elbow-Right hip (f) Elbow-Left hip

Fig. 5. NCC between Elbow Joint Angle and each Joint Angle of Lower Body.



(a) Wrist-Right ankle (b) Wrist-Left ankle (c) Wrist-Right knee (d) Wrist-Left knee (e) Wrist-Right hip (f) Wrist-Left hip

Fig. 6. NCC between Wrist Joint Angle and each Joint Angle of Lower Body.

Right hip joint angle ($\theta_{r.hip}(t)$) was calculated with $\mathbf{v}_{M6,M4}(t)$ and $\mathbf{v}_{M6,M8}(t)$. Left hip joint angle ($\theta_{l.hip}(t)$) was calculated with $\mathbf{v}_{M7,M5}(t)$ and $\mathbf{v}_{M7,M9}(t)$. Right knee joint angle ($\theta_{r.knee}(t)$) was calculated with $\mathbf{v}_{M8,M6}(t)$ and $\mathbf{v}_{M8,M10}(t)$. Left knee joint angle ($\theta_{l.knee}(t)$) was calculated with $\mathbf{v}_{M9,M7}(t)$ and $\mathbf{v}_{M9,M11}(t)$. Right ankle joint angle ($\theta_{r.ankle}(t)$) was calculated with $\mathbf{v}_{M10,M8}(t)$ and $\mathbf{v}_{M10,M12}(t)$. Left ankle joint angle ($\theta_{l.ankle}(t)$) was calculated with $\mathbf{v}_{M11,M9}(t)$ and $\mathbf{v}_{M11,M13}(t)$.

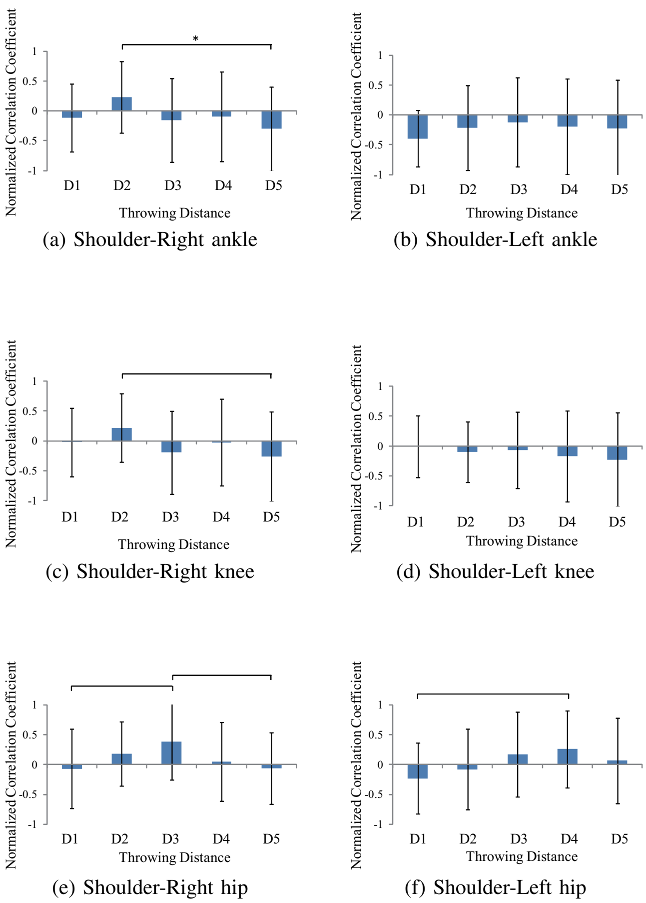
IV. Results

Joint correlation analysis was applied to the data measured in each trial. Figure 5 shows the results of NCC analysis between elbow joint angle and each joint angle of lower body ($\mathrm{NCC}^{\mathrm{elbow}}_{\mathrm{r.ankle,l.ankle,r.knee,l.knee,r.hip,l.hip}}$) at each throwing distance. Figure 6 shows the results of NCC analysis between wrist joint angle and each joint angle of lower body ($\mathrm{NCC}^{\mathrm{wrist}}_{\mathrm{r.ankle,l.ankle,r.knee,l.knee,r.hip,l.hip}}$) at each throwing distance. Figure 7 shows the results between shoulder joint angle and each joint angle of the lower body ($\mathrm{NCC}^{\mathrm{shoulder}}_{\mathrm{r.ankle,l.ankle,r.knee,l.knee,r.hip,l.hip}}$) at each throwing distance. In these three figures, NCC at each distance were averaged among three participants and error bars show a standard deviation of each data. Figure 8 shows results of averaged SCC between elbow joint angle and right-and-left ankle joint angle ($\mathrm{SCC}^{\mathrm{elbow}}_{\mathrm{r.ankle}}$ and $\mathrm{SCC}^{\mathrm{elbow}}_{\mathrm{l.ankle}}$),and SCC between elbow joint angle and right-and-left knee joint angle ($\mathrm{SCC}^{\mathrm{elbow}}_{\mathrm{r.knee}}$ and $\mathrm{SCC}^{\mathrm{elbow}}_{\mathrm{l.knee}}$) at each throwing distance. Table I shows averaged value of $\mathrm{SCC}^{\mathrm{elbow}}_{\mathrm{r.ankle,l.ankle,r.knee,l.knee}}$ for each distance. In the figures, arrows above bars denote two throwing distances in which there were statistical significance ($p < 0.05$).

A. Results of Arm-Lower Body Joint Correlation Analysis

Based on the results of the statistical analysis on $\mathrm{NCC}^{\mathrm{elbow}}_{\mathrm{r.ankle}}$, $\mathrm{NCC}^{\mathrm{elbow}}_{\mathrm{r.knee}}$ and $\mathrm{NCC}^{\mathrm{elbow}}_{\mathrm{l.knee}}$, the degrees of the correlation were increased at throwing long distance (D3, D4 and D5). On the other hand, based on the results of the statistical analysis on $\mathrm{NCC}^{\mathrm{wrist}}_{\mathrm{r.ankle,l.ankle,r.knee,l.knee,r.hip,l.hip}}$ and $\mathrm{NCC}^{\mathrm{shoulder}}_{\mathrm{r.ankle,l.ankle,r.knee,l.knee,r.hip,l.hip}}$, the degree of correlation is ruleless between throwing long distance and throwing short distance.

In Fig. 8 and Table I, at throwing long distance, $\mathrm{SCC}^{\mathrm{elbow}}_{\mathrm{r.knee}}$ were lower than $\mathrm{SCC}^{\mathrm{elbow}}_{\mathrm{r.ankle}}$, $\mathrm{SCC}^{\mathrm{elbow}}_{\mathrm{l.ankle}}$, and $\mathrm{SCC}^{\mathrm{elbow}}_{\mathrm{l.knee}}$.



(a) Shoulder-Right ankle (b) Shoulder-Left ankle
(c) Shoulder-Right knee (d) Shoulder-Left knee
(e) Shoulder-Right hip (f) Shoulder-Left hip

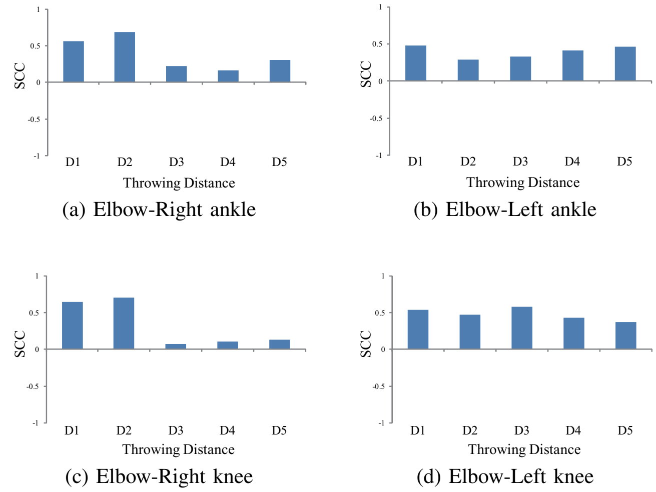
Fig. 7. NCC between Shoulder Joint Angle and each Joint Angle of Lower Body.

TABLE I
SCC DURING EACH DISTANCE

	Trial	SCC		Trial	SCC
	D1	0.56		D1	0.48
	D2	0.68		D2	0.29
Elbow-Right ankle	D3	0.23	Elbow-Left ankle	D3	0.33
	D4	0.17		D4	0.41
	D5	0.30		D5	0.46
	D1	0.64		D1	0.53
	D2	0.70		D2	0.47
Elbow-Right knee	D3	0.07	Elbow-Left knee	D3	0.57
	D4	0.11		D4	0.43
	D5	0.13		D5	0.37

B. Results of Cohen's Criteria Analysis

The magnitude of the joint correlation was defined by the following Cohen's criteria: 0.0-0.1 poor, 0.1-0.3 small, 0.3-0.5 moderate, >0.5 large [21]. Based on Cohen's criteria, the change of throwing motion corresponding to the change of throwing distance was discussed. At throwing distances D1 and D2, the joint correlation between elbow and right hip were higher than one at throwing long distances: D1 is large, D2 is moderate, and D3, D4, and D5 are small. Similarly, at



(a) Elbow-Right ankle (b) Elbow-Left ankle
(c) Elbow-Right knee (d) Elbow-Left knee

Fig. 8. SCC between Elbow and both Ankle and One between Elbow and both Knee.

throwing distance D2, the joint correlation between elbow and left hip were higher than one at throwing long distances: D2 is large, and D3, D4, and D5 are small. The joint correlation between wrist and left ankle were as well: D1 is moderate, D2 is moderate, D3 and D5 are small, and D4 is poor. In addition, at throwing distances D2 and D3, the joint correlation between wrist and right ankle, and between wrist and right knee were higher than one at throwing other distances: D2 is moderate, D3 is moderate, and D1, D4, and D5 are small. At throwing distance D1, the joint correlation between wrist and right hip were higher than one at other distance: D1 is moderate, D2, D3, and D4 are small, D5 is poor. At throwing distances D2, D3, and D4, the joint correlation between wrist and left hip were higher than one at throwing distance D1 and D5: D2, D3, and D4 are moderate, and D1 and D5 are small.

Thus, in order to throw at long distances, throwers utilized a large joint correlation between elbow and ankle, and between elbow and knee. On the other hand, in order to throw at throwing short distances, throwers utilized larger joint correlation between elbow and hip compared to ankle and knee. At throwing distances D2 and D3, larger joint correlation between wrist and lower body was utilized compared to one at throwing distances D4 and D5.

At every throwing distance, joint correlation between shoulder and lower body was small. Thus, the joint correlation between shoulder and lower body was unused during dart throwing motion.

V. DISCUSSION

Based on the results of SCC, the evaluation of the joint correlation with $NCC^{elbow}_{r.knee}$ is the most effective evaluation of the correlation between arm and lower body in dart throwing motion. As a result of the statistical analysis on $NCC^{elbow}_{r.knee}$, there were no statistical significance among D3, D4 and D5 ($p < 0.05$). Thus, in our experiment, it is suggested that a measurement of dart throwing motion at throwing distance D3 is sufficient to evaluate the joint correlation with NCC between arm and lower body.

If dart throwing motion is used for training integrated arm movements and lower body movements, it is desirable that throwing distance was set to 1.2 m, 2.4 m, and 3.6 m. It is suggested that dart throwing motion is more effective for recovery of the joint correlation between elbow flexion and lower body movements at throwing distance D3. Furthermore, in order to recover the joint correlation between wrist movements and lower body movements, it is desirable that throwing distance sets 2.4m–3.6m.

VI. Conclusion

In this study, we investigated joint correlation between arm and lower body during dart throwing motion. A normalized correlation coefficient was used to quantify the joint correlation. At throwing long distance, it is necessary that the correlation between elbow and ankle, and between elbow and knee were increased. This is because at long distance, throwers depend exclusively on the coordination between elbow movement and lower body movement. In addition, for short distance, throwers utilized larger joint correlation between elbow and hip compared to between elbow and ankle, and between elbow and knee. The joint correlation between wrist and lower body was utilized at throwing distances 2.4m and 3.6m. On the other hand, the joint correlation between shoulder and lower body was unused at every throwing distance.

Our study revealed that quantitative evaluation of the joint correlation during dart throwing motion has potential to evaluate coordinative ability between arm and lower body. Thus, we may evaluate the recovery process for coordinative ability with the investigation of joint correlation at throwing short and long distances.

In our future research, we will test our experiment with more subjects and confirm the evaluation of coordination between arm movements and lower body movements. Likewise, we will measure not only body motion trajectory but also surface electromyography in order to investigate muscle coordination between upper body and lower body. In order to propose more effective evaluation of coordinative ability between arm and lower body, we should analyze throwing motion for the case of other two stances of feet (as shown in Fig. 2).

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