

Original Research

Characteristics of High-Impact Movements Observed in High School Handball Players During Games

Nana Kanoshima, M.S.^a, Yasuharu Nagano, Ph.D., Hiroshi Ichikawa, M.S., Shogo Sasaki, Ph.D., Makoto Suzukawa, M.S.

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Background

In handball, injury occurs more frequently during actual games than during handball practice. However, mechanical loading during actual games is unknown.

Purpose

The purpose of this study was to describe body impact characteristics during handball games using accelerometers, and to investigate sex differences in these characteristics.

Study Design

Comparative observational study.

Methods

Acceleration data were measured during practice games in 24 high school handball players (12 males, 12 females). The acceleration was set to 1 gravitational acceleration (G) when each axis direction was aligned with the direction of gravity during data collection. High-impact movements with a resultant acceleration of $\geq 6G$ were extracted, and video images were used to identify movements and plays during which the high-impact movements occurred. The number of cases, percentage, frequency (cases/min $\cdot$ person), and 95% confidence interval of the frequency were calculated for the movement classification, play classification, and movement classification $\times$ play classification. The peak acceleration values of resultant accelerations of $\geq 6G$ were also obtained.

Results

The frequencies of resultant acceleration $\geq 6G$ were 5.3 cases/min $\cdot$ person for males and 4.7 cases/min $\cdot$ person for females. Deceleration and sprinting were the most frequent motion categories in both sexes. High-impact movements were more frequent in fast attack-related play in males and attack-to-defense transitions in females.

Conclusion

High-impact movements are more frequent in plays related to fast attacks in males and when switching from attack to defense in females. High-impact movements are more likely to occur during the switch from attack to defense in females.

Level of evidence

3

^a Corresponding Author:
Nana Kanoshima
3302-5, Kodokuetyou, Kouhoku, Yokohama, Kanagawa, 222-0036, Japan
Tel: +81-45-477-5065
Email: kanoshima.nana@gmail.com

INTRODUCTION

Handball involves three basic sports movements: running, jumping, and throwing. It is fast-paced and involves intense physical contact, resulting in frequent injury.^{1,2} Injury occurs more frequently during games than during handball practice.³⁻⁵ Therefore, the physical load during games should be investigated to prevent or reduce injuries.

Studies^{6,7} on secondary school students and athletes under the age of 18 have reported a trend towards higher incidence of trauma in males. Additionally, trends vary by level of competition and age group—for example, in elite handball players and high school students, females have been reported to have a higher incidence of trauma.^{3,8} Furthermore, female handball players have a higher incidence of anterior cruciate ligament (ACL) injury than that observed among male players.⁴ Hewett et al.⁹ reported that increased knee abduction moment, knee joint external rotation angle, and ground reaction force were predictors of ACL injury. Nagano et al.¹⁰ also investigated sex differences in the trunk tilt angle and knee joint angle during cutting motion and reported that females exhibited a motion pattern similar to that observed during ACL injury. However, other studies have reported no difference in the incidence of injury between sexes,⁴ and there is no consensus owing to differing study participants and methods. Moreover, because these studies were conducted in a laboratory, it is necessary to clarify mechanical loading during actual games.

Recently, body impact has been measured using acceleration sensors as indicators of movement characteristic during games.^{11,12} The resultant acceleration can be calculated from acceleration data, making it possible to define high-impact movements. Acceleration sensors can measure high-impact movements during actual games without restricting the athlete's movements or examining the circumstances under which high-impact movements occur.

A systematic review of handball injuries and disabilities found that the severity of injury in females was higher in noncontact situations than in contact situations, whereas in males, the most severe injuries occurred in contact situations.⁵ The Authors believe that studying sex differences in mechanical loading during games will provide new insights into sex differences in trauma and injury. Therefore, this study aimed to describe body impact characteristics during handball games using accelerometers, and to investigate sex differences in these characteristics.

It was hypothesized that the frequency of high-impact movements would be higher in females than in males during games because females are more likely than males to experience ACL injuries.

MATERIALS AND METHODS

PARTICIPANTS

Twenty-four (12 males and 12 females) high school handball players were recruited from two all-male and two all-female teams. At the time of this study, the participants



Figure 1. Accelerometer

and their guardians were fully informed orally and in writing of the nature of this study and its anticipated risks, and their consent to participate was obtained in writing. This study was approved by the Research Ethics Committee of the Japan Women's College of Physical Education (approval number 2021-2).

MOTION MEASUREMENT

An accelerometer (SS-WS1201, Sports Sensing, Fukuoka, Japan) was attached to the upper back of each participant (Figure 1) and secured using a special vest (Figure 2). Each participant wore a compressible inner shirt to prevent the sensor from shifting because of body movements or vibrations. The X-, Y-, and Z-axes indicate the left/right, up/down, and forward/backward directions, respectively. The acceleration of the sensors was set to 1G when each axis was oriented in the direction of gravity, using the same method as in a previous study¹³ that measured acceleration during games using accelerometers. While wearing the accelerometer, the participants played one practice games against another school for 30 min (males) or 25 min (females), and the acceleration during the match was measured at 200 Hz. Practice games are scrimmages, not official games. The measured data were saved in the accelerometer memory. After the measurements were obtained, the accelerometers were collected and the data were imported into a personal computer and analyzed using dedicated analysis software. The entire handball court was filmed using three video cameras (GZ-RX600, JVC, Kanagawa, Japan) (Hero4, GoPro company, CA, USA), and participants' motion was recorded at 60 Hz while the acceleration data were measured. The video data were synchronized using a light-emitting device (LP-WSYLT1, LOGICAL PRODUCT, Fukuoka, Japan) at the start of acceleration data measurement.

DATA ANALYSIS

The resultant acceleration ($= \sqrt{X^2 + Y^2 + Z^2}$) was calculated from the measured resultant acceleration data, and

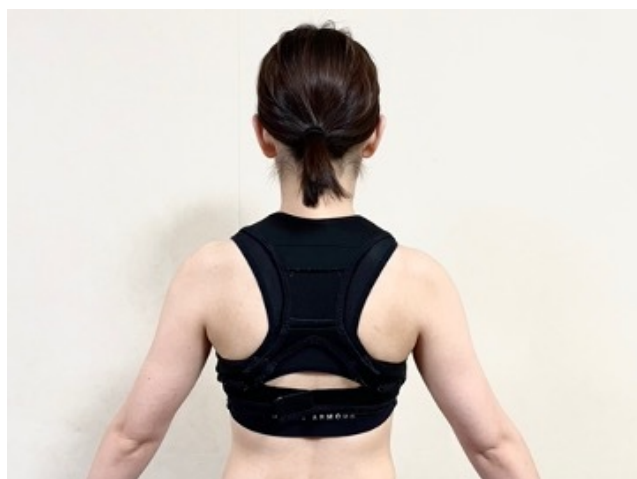


Figure 2. Accelerometer special vest, worn by female and male subjects

the cases and frequency (cases/min · person) where the resultant acceleration exceeded 6G and the composite acceleration values were calculated. From previous research,^{13, 14} when a threshold of 4G or higher is considered a high-impact movement, a large proportion of simple running and moving movements back and forth across the court are extracted. Many of these movements do not reflect the characteristics of the sport; so, in this study, 6G or higher was defined as a high-impact movement for analysis. The movements and plays with resultant acceleration exceeding 6G were classified and tabulated using a tagging software (Dartfish software, Dartfish Japan) based on synchronized video images. Movements were classified as running, sprint, swing, deceleration, acceleration, stop, change of direction, forward step, side step, back step, cross step, step off, landing, falling, contact, others, and unknown ([Table 1](#)), based on previous studies.¹⁵ Play classification was based on the following categories: passing, pass catching, shooting, cutting, dribbling, positioning, fast attack, fast attack defense, transition to defense, transition to attack, shut, block, loose ball, rebound, pass cutting, on-ball defense, off-ball defense, back to the bench, others, and unknown ([Table 2](#)).

The number of cases, percentage of total cases, frequency (cases/min · person), and the 95% confidence interval (95% CI = frequency $\pm$ 1.96*[frequency/ $\sqrt{\text{number of cases}}$])¹⁶ of the frequency were calculated for motion classification, play classification, and motion classification · play classification. The independent variables include movement classification, play classification, and sex, while the dependent variable is acceleration. Additionally, peak acceleration values were calculated when the resultant acceleration was $\geq$ 6G.

Statistical analysis was performed using a two-way analysis of variance (play-movement $\times$ sex) with IBM SPSS Statistics version 19 (IBM, Tokyo, Japan) to examine the main effect of play-movement and its interaction. For variables in which the main effect of play-movement was significant, the Bonferroni method was used as a post-test, and the peak acceleration values of the resultant accelera-

tion were compared. Statistical significance was set at $\alpha = 0.05$.

RESULTS

Participants' individual characteristics are presented in [Table 3](#). Regarding cases with resultant acceleration $> 6G$, 1,799 cases were extracted for the male participants during their total playing time of 337.1 min (5.3 cases/min · person [95% CI, 5.1–5.6]), whereas 1,345 cases were identified for the female participants during their 287.6 min of playing time (4.7 cases/min · person [95% CI, 4.4–4.9]). In terms of movement classification ([Table 4](#)), deceleration (29.5%) was the most frequent movement among male participants, followed by sprinting (19.3%) and changes in direction (9.6%). Deceleration was the most frequent movement among female participants (28.5%), followed by sprinting (27.3%) and stopping (8.4%). In terms of the classification of play ([Table 5](#)), fast attacks were most common among males (22.3%), followed by fast attack defense (17.6%) and transition to defense (10.4%). Among females, the transition to defense was the most frequent (21.8%), followed by fast attack defense (19.8%) and fast attack (17.9%).

PLAY CLASSIFICATION $\times$ MOVEMENT CLASSIFICATION

The frequencies of $\geq 6G$ play classification $\times$ movement classification among males were 0.5 cases/person · min (95% CI, 0.4–0.6) in deceleration in fast attack, 0.4 cases/person · min (95% CI, 0.3–0.5) in sprint in fast attack, and 0.4 cases/person · min (95% CI, 0.3–0.5) in deceleration in fast attack defense ([Table 6](#)). However, the frequencies of $\geq 6G$ play classification $\times$ movement classification among females were 0.5 cases/min · person (95% CI, 0.4–0.6) in deceleration in transition to defense, 0.5 cases/min · person (95% CI, 0.4–0.5) in deceleration in fast attack, and 0.4 cases/min · person (95% CI 0.4–0.5) in sprint in fast attack defense ([Table 7](#)).

PEAK ACCELERATION VALUES FOR HIGH-IMPACT MOVEMENTS

There was a significant interaction between males and females in terms of peak acceleration values during high-impact movements ($p = 0.048$). Males' peak resultant acceleration values were $8.1 \pm 1.8G$ for deceleration in fast attack defense and $8.1 \pm 1.8G$ for deceleration of fast attack. For females, the peak resultant acceleration value was $8.2 \pm 2.0G$ and occurred during the change of direction in the transition to defense ([Table 8](#)).

Multiple comparisons revealed that peak acceleration values were higher for females than for males in the change of direction during the transition to defense ($p = 0.012$). Comparisons between movements showed that peak acceleration values were higher for males in deceleration in fast attack than in sprinting during the transition to defense ($p < 0.001$), sprinting in fast attack ($p < 0.001$), sprinting in fast attack defense ($p = 0.001$), and turning back in fast attack defense ($p = 0.018$). Peak acceleration values were higher in

Table 1. Movement classification definitions

Running	A movement where the player moves forward or backward at a steady pace.
Sprint	A movement where the player runs at high speed.
Swing	A movement where the arm is rapidly moved in an arc to pass or shoot the ball.
Deceleration	A movement where the player reduces speed quickly.
Acceleration	A movement where the player increases speed rapidly.
Stop	A movement where the player comes to a complete halt from motion.
Change of direction	A movement where the player quickly shifts their path to a new angle.
Forward step	A movement where the player steps forward with one foot to advance.
Side step	A movement where the player moves laterally by stepping with one foot.
Back step	A movement where the player steps backward with one foot to create space.
Cross step	A movement where one foot steps across the other to change direction.
Step off	A movement where the player pushes off the ground to initiate a jump.
Landing	A movement where the player returns to the ground after a jump.
Falling	A movement where the player collapses to the ground.
Contact	A movement where the player makes physical contact with an opponent.
Others	Movements that do not fit into the defined categories.
Unknown	Movements occurring outside the court and not captured in the image.

Table 2. Play classification definitions

Passing	An action where the player throws the ball to a teammate.
Pass catching	An action where the player catches the ball.
Shooting	An action where the player throws the ball toward the goal.
Cutting	An action where the player changes direction sharply to attack.
Dribbling	An action where the player bounces the ball while moving.
Positioning	An action where the player positions themselves for the next play.
Fast attack	An action where the player advances the ball before defense is set.
Fast attack defense	An action where the player moves to stop a fast attack.
Transition to defense	An action where the player moves from attack to defense.
Transition to attack	An action where the player moves from defense to attack.
Shut	An action where the player raises their hands to defend a shot.
Block	An action where the player impedes an opponent's movement.
Loose ball	An action where the player tries to gain an uncontrolled ball.
Rebound	An action where the player gains possession after a missed shot.
Pass cutting	An action where the player intercepts an opponent's pass.
On-ball defense	An action where the player defends against the ball carrier.
Off-ball defense	An action where the player defends against a player without the ball.
Back to the bench	An action where the player returns to the bench area.
Others	Actions that do not fit into the defined categories.
Unknown	Actions occurring outside the court and not captured in the image.

deceleration in fast attack defense compared with those in sprinting in transition to defense ($p < 0.001$), sprinting in fast attack ($p < 0.001$), sprinting in fast attack defense ($p = 0.003$), and turning back in fast attack defense ($p = 0.025$). Contact in on-ball defense occurred more frequently than sprinting in the transition to defense ($p < 0.001$), sprinting in fast attack defense ($p < 0.001$), and turning back in fast

attack defense ($p = 0.025$) and had a higher peak value than that observed during sprinting in the transition to defense ($p = 0.011$). For females, the peak acceleration values were higher for deceleration in fast attack than for sprinting in the transition to defense ($p < 0.001$), sprinting in fast attack ($p = 0.033$), and turning back in fast attack defense ($p < 0.001$). The change in direction from transition to defense

Table 3. Demographic characteristics

	Male (n = 12)	Female (n = 12)
Age (years)	16.8 ± 0.8	16.8 ± 0.4
Height (cm)	172.2 ± 4.6	164.0 ± 6.7
Body mass (kg)	68.7 ± 5.7	57.9 ± 5.3
Handball career (years)	5.5 ± 3.0	4.5 ± 1.6
Dominant hand	R: n = 10, L: n = 2	R: n = 11, L: n = 1

R, right; L, left

had a higher peak value than that observed for sprints in transition to defense ($p = 0.043$) or sprints in fast attack defense ($p = 0.006$). Deceleration in fast attack defense had a higher peak value than sprinting ($p = 0.004$).

DISCUSSION

In this study, males exhibited a higher frequency of high-impact movements during the handball games than females, which may be because of the increased number of fast attacks and shots. In many cases, males also fell down to shoot, and the percentage of falling was higher for males than for females, indicating a difference in playing style between sexes.

For both sexes, high-impact motion was recorded at a high frequency during deceleration and sprinting, followed by a change in direction and a stopping motion. These results are consistent with those reported by Olsen et al.,⁴ who showed that it was possible to extract trauma-prone movements in handball using accelerometers.

In terms of play classification, the frequency of high-impact movements among males was in the following order: fast attack, fast attack defense, and transition to defense. It is thought that high-impact movements are more frequent in plays related to fast attacks and that deceleration, sprinting, and turning back are more frequent in such plays. Among the female players, the frequency of high-impact movements was higher in the order of transition to defense, fast attack defense, and fast attack. The frequency of high-impact movements during the attack-to-defense transition was high, and the characteristics of frequent deceleration and stopping movements were not limited to fast attacks.

PLAY CLASSIFICATION × MOVEMENT CLASSIFICATION

The current results demonstrated that deceleration and sprinting associated with fast attacks were more frequent in males than in females, whereas deceleration and sprinting associated with defense were more frequent in females than in males. The peak acceleration values of the resultant acceleration were the highest for both sexes in the deceleration of a fast attack at $8.0 \pm 1.8G$, indicating that this is the most physically impactful movement in handball. Deceleration of a fast attack and deceleration in fast attack defense both showed peak acceleration values of $8.1 \pm 1.8G$ for both sexes. However, females showed a peak value of $8.2 \pm 2.0G$ for the change of direction in transition to defense, and

the results differed between the sexes. Differences cannot be explained solely by the difference in body mass between females and male subjects. Biomechanical characteristics during movement such as knee valgus may influence how forces are generated and absorbed during change-of-direction movements, potentially contributing to the higher peak acceleration values observed in females during the transition to defense in the present study.

Future work should include comparisons of high-impact movements between defensive and offensive forms, position-by-position comparisons, and prospective studies on the relationship among trauma, injury occurrence, and trunk acceleration.

LIMITATIONS

This study has a few limitations. First, the measurements were taken in practice matches, not official matches. These were not exhibition matches, but semi-official matches against other teams. Therefore, the intensity of the matches measured in this study is assumed to be close to that of official matches. Additionally, the analysis was limited to one match each for men and women. However, no other study has examined impact and movements during a handball match in such detail. Future studies should examine multiple matches and examine changes due to match conditions and opponents. Second, the measurement times differed between males and females. Although it is possible that the observed differences were caused by fatigue or other factors, as the main results of this study were calculated as frequency per time, no significant influence is considered to be expected. Third, as the study utilized body impact data from accelerometers attached to the trunk, the data could not be used to interpret the direct impact on the knee joints or other parts of the body.

CONCLUSIONS

In handball, high-impact movements are required for deceleration, sprinting, direction change, and stopping by both males and females. Reflecting on the style of play, high-impact movements are more frequent in plays related to fast attacks in males and when switching from attack to defense in females. Moreover, the peak acceleration values of the composite acceleration are the highest in the deceleration of a fast attack for males and in the change of direction during the transition to defense for females, demon-

Table 4. Classification of movement during handball games. Frequency is defined as number of high impact movements that occurred per minute.

Movement	Male				Female			
	Case	Percentage	Frequency	95% CI	Case	Percentage	Frequency	95% CI
Deceleration	530	29.5	1.6	1.4-1.7	383	28.5	1.3	1.2-1.5
Sprint	347	19.3	1.0	0.9-1.1	367	27.3	1.3	1.1-1.4
Change of direction	173	9.6	0.5	0.4-0.6	101	7.5	0.4	0.3-0.4
Stop	113	6.3	0.3	0.3-0.4	113	8.4	0.4	0.3-0.5
Contact	107	5.9	0.3	0.3-0.4	65	4.8	0.2	0.2-0.3
Falling	74	4.1	0.2	0.2-0.3	28	2.1	0.1	0.1-0.1
Cross step	68	3.8	0.2	0.2-0.2	34	2.5	0.1	0.1-0.2
Side step	69	3.8	0.2	0.2-0.3	75	5.6	0.3	0.2-0.3
Swing	8	0.4	0.0	0.0-0.0	3	0.2	0.0	0.0-0.0
Forward step	33	1.8	0.1	0.1-0.1	51	3.8	0.2	0.1-0.2
Back step	19	1.1	0.1	0.0-0.1	8	0.6	0.0	0.0-0.0
Acceleration	1	0.1	0.0	0.0-0.0	0	0.0	0.0	-
Running	58	3.2	0.2	0.1-0.2	39	2.9	0.1	0.1-0.2
Landing	56	3.1	0.2	0.1-0.2	25	1.9	0.1	0.1-0.1
Step off	34	1.9	0.1	0.1-0.1	15	1.1	0.1	0.0-0.1
Others	27	1.5	0.1	0.0-0.1	3	0.2	0.0	0.0-0.0
Unknown	82	4.6	0.2	0.2-0.3	35	2.6	0.1	0.1-0.2
Total	1799	100.0	5.3	5.1-5.6	1345	100.0	4.7	4.4-4.9

CI, confidence interval

Table 5. Classification of play during handball games. Frequency is defined as number of high impact movements that occurred per minute.

Play	Male				Female			
	Case	Percentage	Frequency	95% CI	Case	Percentage	Frequency	95% CI
Fast attack	401	22.3	1.2	1.1–1.3	241	17.9	0.8	0.7–0.9
Fast attack defense	317	17.6	0.9	0.8–1.0	266	19.8	0.9	0.8–1.0
Transition to defense	187	10.4	0.6	0.5–0.6	293	21.8	1.0	0.9–1.1
Positioning	140	7.8	0.4	0.3–0.5	113	8.4	0.4	0.3–0.5
Shooting	125	6.9	0.4	0.3–0.4	53	3.9	0.2	0.1–0.2
Back to the bench	40	2.2	0.1	0.1–0.2	24	1.8	0.1	0.1–0.1
Transition to attack	34	1.9	0.1	0.1–0.1	17	1.3	0.1	0.0–0.1
Off-ball defense	124	6.9	0.4	0.3–0.4	69	5.1	0.2	0.2–0.3
On-ball defense	119	6.6	0.4	0.3–0.4	57	4.2	0.2	0.1–0.2
Cutting	81	4.5	0.2	0.2–0.3	53	3.9	0.2	0.1–0.2
Shut	9	0.5	0.0	0.0–0.0	2	0.1	0.0	0.0–0.0
Dribbling	10	0.6	0.0	0.0–0.0	6	0.4	0.0	0.0–0.0
Passing	58	3.2	0.2	0.1–0.2	49	3.6	0.2	0.1–0.2
Pass cutting	4	0.2	0.0	0.0–0.0	0	0.0	0.0	–
Pass catching	29	1.6	0.1	0.1–0.1	33	2.5	0.1	0.1–0.2
Block	9	0.5	0.0	0.0–0.0	26	1.9	0.1	0.1–0.1
Block (defense)	0	0.0	0.0	–	1	0.1	0.0	0.0–0.0
Rebound	2	0.1	0.0	0.0–0.0	3	0.2	0.0	0.0–0.0
Loose ball	7	0.4	0.0	0.0–0.0	1	0.1	0.0	0.0–0.0
Others	25	1.4	0.1	0.0–0.1	3	0.2	0.0	0.0–0.0
Unknown	78	4.3	0.2	0.2–0.3	35	2.6	0.1	0.1–0.2
Total	1799	100.0	5.3	5.1–5.6	1345	100.0	4.7	4.4–4.9

CI, confidence interval

Table 6. Play classification × movement classification (male). Frequency is defined as number of high impact movements that occurred per minute.

Play	Movement	Case	Frequency	95% CI
Fast attack	Deceleration	169	0.5	0.4–0.6
Fast attack	Sprint	141	0.4	0.3–0.5
Fast attack defense	Deceleration	140	0.4	0.3–0.5
Fast attack defense	Sprint	102	0.3	0.2–0.4
Transition to defense	Deceleration	73	0.2	0.2–0.3
Transition to defense	Sprint	63	0.2	0.1–0.2
Positioning	Deceleration	62	0.2	0.1–0.2
On-ball defense	Contact	43	0.1	0.1–0.2
Fast attack defense	Change of direction	36	0.1	0.1–0.1
Transition to defense	Change of direction	30	0.1	0.1–0.1

CI, confidence interval

Table 7. Play classification × movement classification (female). Frequency is defined as number of high impact movements that occurred per minute.

Play	Movement	Case	Frequency	95% CI
Transition to defense	Sprint	153	0.5	0.4–0.6
Fast attack	Deceleration	133	0.5	0.4–0.5
Fast attack defense	Sprint	123	0.4	0.4–0.5
Fast attack defense	Deceleration	93	0.3	0.3–0.4
Fast attack	Sprint	80	0.3	0.3–0.4
Transition to defense	Deceleration	73	0.3	0.2–0.3
Positioning	Deceleration	36	0.1	0.1–0.2
Fast attack defense	Change of direction	35	0.1	0.1–0.2
Transition to defense	Change of direction	29	0.1	0.1–0.1
On-ball defense	Contact	19	0.1	0.0–0.1

CI, confidence interval

Table 8. Peak acceleration values of play classification × movement classification

Play	Movement	Peak acceleration values (G ± SD)		
		Male	Female	p-value
Transition to defense	Sprint	6.9 (± 0.7)	7.2 (± 1.2)	0.209
Transition to defense	Deceleration	7.5 (± 1.1)	7.6 (± 1.7)	0.566
Transition to defense	Change of direction	7.2 (± 1.3)	8.2 (± 2.0)	0.012*
On-ball defense	Contact	8.0 (± 2.2)	7.5 (± 3.5)	0.259
Positioning	Deceleration	7.6 (± 1.5)	7.5 (± 1.5)	0.759
Fast attack	Sprint	7.3 (± 1.2)	7.2 (± 1.0)	0.790
Fast attack	Deceleration	8.1 (± 1.8)	7.9 (± 1.8)	0.275
Fast attack defense	Sprint	7.3 (± 1.2)	7.0 (± 1.1)	0.066
Fast attack defense	Deceleration	8.1 (± 1.8)	7.8 (± 1.6)	0.090
Fast attack defense	Change of direction	7.1 (± 1.2)	7.5 (± 1.4)	0.361

* Statistically significant

strating that high-impact movements differ depending on sex.

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