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ORIGINAL ARTICLE

# Characteristics of body movements and ground reaction forces during the follow-through phase in baseball

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## ABSTRACT

In baseball, batters run to first base after hitting the ball, meaning the batting motion following impact may transition into running motion. This study aimed to clarify the characteristics of ground reaction forces (GRF) and body movements related to base running by comparing batting and running conditions (BRC) with batting-only conditions (BC) during the follow-through phase (FT phase). Thirteen right-handed male university baseball players participated. Using motion capture and force plates, the players batted at inside, middle, and outside pitch locations under both conditions. During the FT phase, BRC showed a decrease in GRF on the stride side and an increase in GRF on the axis side compared to BC. Shoulder and hip rotation angles and angular velocities were significantly lower in BRC. Furthermore, whole-body centre of gravity displacement was significantly higher in BRC for pitches on the middle and outside corners. These results suggest that the FT phase contributes not only to the completion of the swing but also to the initiation of base running.
**Keywords**: Performance analysis, Sports performance, Simple motor skill, Complex motor skill, Situation integration.

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## INTRODUCTION

Various body movements can be categorized into simple motor skills and complex motor skills. According to Yamamoto (2004), simple motor skills correspond to individual actions, whereas complex motor skills refer to continuous movements involving repeated individual actions or the transition and continuation between multiple actions.

Generally, in baseball, throwing and batting are considered simple motor skills. Although the term "*simple motor skills*" has not always been used in previous studies, many have been conducted from this perspective. However, throwing and batting may become complex motor skills when linked with other actions, and most movements in game situations can be considered complex motor skills. For example, in throwing, the action becomes catching-throwing when combined with catching, and in batting, it becomes batting-running when combined with running to first base. Therefore, while studies focusing on simple motor skills remain important, it is possible that they differ from the complex motor skills observed in actual baseball games.

Regarding the structure of complex motor skills, Kinoshita (1993) suggests that when two actions are combined, they eventually form a unified whole that is functionally interconnected. Furthermore, in complex motor skills, a transitional phenomenon known as the "*intermediate phase*" occurs at the junction of the end phase of the preceding action and the preparation phase of the subsequent action. In the case of the complex motor skill involving catching and throwing, this intermediate phase refers to how the arm movement during catching transforms into a preparatory motion for throwing (Kinoshita, 1993). The purpose of this transformation is to connect the two actions smoothly and more efficiently. Murase et al. (2016) compared simple catching movements with complex movements that involve catching followed by a backward throw, and found that in the complex movements, the rotation angles of the shoulders and hips were more oriented toward the pitcher, indicating that the end phase of catching was already linked with the preparation phase of throwing. This implies that the movement changed according to the purpose of the next action—throwing—and suggests the possibility that in the Follow-through Phase (FT Phase) after impact in batting, the movement may also transform depending on the purpose of transitioning into base running. However, this possibility has not been thoroughly examined in previous studies.

One reason for the scarcity of research on the intermediate phase from the FT Phase to the initial base running phase is that, according to Horiuchi & Nakashima (2024), most studies on batting have focused on the pre-impact phase. Additionally, many studies on base running have examined sprinting from a standing start to first base, often focusing on running speed. As a result, the intermediate phase has not received much attention. Therefore, clarifying the body movements during the FT Phase as they connect to the initial phase of base running could provide foundational insights into the intermediate phase and offer new perspectives on efficient transitions into base running after impact.

In baseball, batters are generally classified as right-handed or left-handed. Mann et al. (2017) noted that among right-handed players, those who bat left-handed tend to open their bodies toward first base after swinging, facilitating a faster start. This environment seems advantageous for left-handed batters, and it is thought that many fast runners are left-handed, possibly because they can reduce the time required to transition from batting to base running, which is critical for reaching base. Conversely, right-handed batters tend to open their bodies toward third base and compared to left-handed batters, face a longer distance to first base, making it more difficult to transition into running. Furthermore, when right-handed batters swing at different pitch locations (Inside, Middle, Outside), the Inside pitch tends to require greater trunk rotation toward third base during and after impact, which may hinder a quick transition to running compared to other pitches. If the characteristics of right-handed batters who can perform quick transitions can be identified, it would provide valuable information on the intermediate phase, which has not been emphasized in prior studies.

Therefore, the purpose of this study was to focus on the FT Phase during the intermediate phase for right-handed batters and to compare body movements involved in complex and simple motor skills.

## METHODS

### *Participants*

Thirteen healthy male collegiate right-handed baseball players (height: 170.9 ± 4.1 cm, weight: 74.3 ± 4.4 kg) participated in this study. Each participant performed trials under two conditions: Batting and Running Condition (BRC), which involved running after batting, and Batting Condition (BC), which involved batting only. This study was approved by the Ethics Committee of the National Institute of Fitness and Sports in Kanoya (Approval number: 23-1-35). The participants were informed of the purpose, content, confidentiality, and potential risks of the study, and each provided written informed consent.

### *Data collection and processing*

The experiment was conducted at the SPORTEC Sports Performance Research Center of the National Institute of Fitness and Sports in Kanoya. After sufficient warm-up, participants wore spiked shoes and performed batting on a batter’s box integrated with force plates (Yanai et al., 2017). Balls were tossed to three different pitch locations (Inside, Middle, Outside), standardized at waist height for each participant. Both BRC and BC were tested, with three trials per pitch location for each condition, totalling 18 recorded trials per participant.

Ball tosses were executed by the same examiner, with pitch location randomized using a pre-generated random number table. The pitch location was not disclosed to the participant in advance. After each toss, another examiner behind home plate confirmed the pitch location, and any trials not matching the intended course were excluded based on joint examiner judgment.

Participants were instructed to “*swing strongly and run quickly after batting*” in the BRC, and to “*swing strongly*” in the BC.

A total of 52 reflective markers were attached 47 to various body parts and 5 to the bat. An optical motion capture system, Mac3D (Motion Analysis Corporation, Santa Rosa, California, USA; 16 Raptor-E cameras, 500 Hz), and force plates (TF-90100, Tec Gihan, Uji, Japan; 2000 Hz) were used to collect data. Calibration of the 16 cameras resulted in a mean 3D coordinate error of less than 1 mm. Force plate data were transferred via a centralized hub (Tec Gihan, Uji, Japan) and input into the Cortex 8.0.1 software (Motion Analysis Corporation).

The coordinate axes were defined as follows: X-axis from the right batter’s box to the left, Y-axis from home plate toward the pitcher, and Z-axis vertical. For analysis, one trial per participant was selected based on introspective reports indicating the highest subjective performance, following the method of Ae et al. (2013). Three-dimensional coordinate data were smoothed using a second-order Butterworth low-pass filter with a cutoff frequency of 3 Hz, based on previous studies (Nakayama et al., 2007 ; Yamamoto, 2007). Ground reaction force data were down sampled to 500 Hz using a third-order spline function to match the coordinate data for the analysed phase.

### ***Data calculation items and calculation method***

*Ground reaction force during striking motion*

Participants placed their left and right feet on two force plates installed in the right-handed batter's box, and the ground reaction forces (GRFs) along the X, Y, and Z axes were recorded during the motion. The resultant GRF for both the stride-side and pivot-side legs was calculated by combining the X, Y, and Z components. The GRF values were normalized by the participant's body weight (Orishimo et al., 2023).

*Angle of shoulder and hip rotation and angular velocity of shoulder and hip rotation*

The definitions of shoulder and hip rotation angles were partially modified based on previous studies(Nakayama et al., 2007 ; Yamamoto, 2007). For the shoulder vector, a vector was constructed from the right shoulder joint centre to the left shoulder joint centre. For the hip vector, hip joint centres were estimated using the method proposed by the Clinical Gait Analysis Study Group (Kurabayashi et al., 2003), and a vector was created from the right to the left hip joint centre. These vectors were projected onto the XY plane, and the angle with respect to the X-axis was defined as the rotation angle for both shoulder and hip. Angular velocity was calculated by differentiating the rotation angle with respect to time.

*Body centre of gravity position and centre of gravity velocity*

Based on the three-dimensional coordinate data obtained from the motion capture system, the body was modelled using a 15-segment link model including hands, forearms, upper arms, feet, lower legs, thighs, head, upper trunk, and lower trunk. This modelling used segmental inertial parameters defined by Ae (1996). The whole-body centre of mass (CM) position was projected onto the XY plane, and the horizontal component was used to calculate the whole-body centre of mass displacement (CM displacement) and velocity (CM velocity), referring to the method of Takagi et al. (2008). CM velocity was calculated by differentiating CM displacement with respect to time, and the resulting time series was normalized to 100% using a third-order spline curve.

*Phases of operation and data processing*

The analysis phase (Figure 1) was defined from one frame after the moment of ball impact to the point when the virtual marker placed at the midpoint of the bat tip reached its minimum Y-axis value (indicating swing completion). Time-series data were averaged across all participants, with the frame immediately following impact set to 1% and the frame at minimum Y-axis value set to 100%. The data were normalized using interpolation with a third-order spline function.

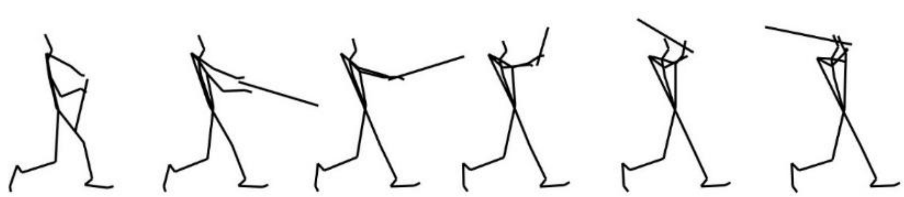

Figure 1 Analysis phase.

### ***Statistical processing***

This study aimed to compare the two conditions, BRC and BC. Therefore, paired t-tests were used to examine significant differences for each calculated variable between the two conditions. For time-series data, any time points showing significant differences between the two conditions are marked in the figures. The level of significance was set at $p < .05$. All statistical analyses were performed using IBM SPSS Statistics 28.0 (Version 28, IBM, Armonk, NY, USA).

## RESULTS

### *Resultant Ground reaction force*

Figure 2 shows the resultant ground reaction force (GRF) for both the stride-side and pivot-side. On the stride-side, the BRC condition exhibited significantly lower GRF values compared to the BC condition in the following intervals: from 54% to 100% of the FT Phase for the Inside pitch, from 34% to 100% for the Middle pitch, and from 25% to 100% for the Outside pitch. Conversely, on the pivot-side, the BRC condition showed significantly higher GRF values than the BC condition from 77% to 100% of the FT Phase for the Middle pitch and from 46% to 100% for the Outside pitch.

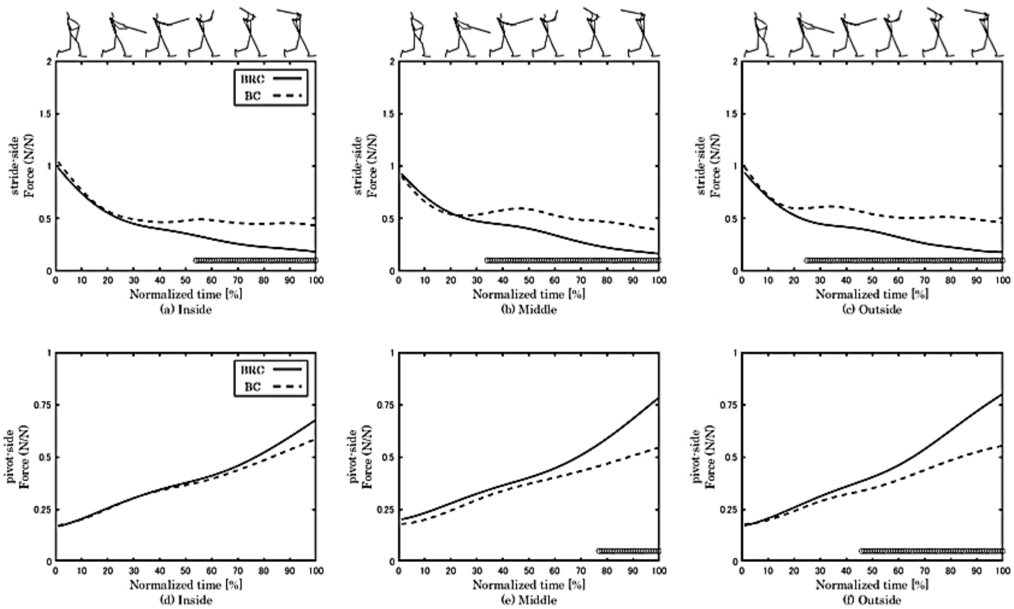

Figure 2 Time series data of Resultant ground reaction force at the time of impact under each condition: (a) Inside stride-side Resultant ground reaction force, (b) Middle stride-side Resultant ground reaction force, (c) Outside stride-side Resultant ground reaction force, (d) Inside pivot-side Resultant ground reaction force, (e) Middle pivot-side Resultant ground reaction force, and (f) Outside pivot-side Resultant ground reaction force.

### *Horizontal, anterior / posterior and vertical GRF*

Figure 3 shows the horizontal, anterior/posterior, and vertical GRF on the stride-side under each condition. In the horizontal component for the Outside pitch, the BRC condition showed significantly higher values than the BC condition from 1% to 16% of the FT Phase. In the posterior component, the BRC condition showed significantly lower values than the BC condition from 60% to 100% for the Inside pitch, from 38% to 100% for the Middle pitch, and from 34% to 100% for the Outside pitch. In the vertical component, the BRC condition exhibited significantly higher values than the BC condition from 54% to 100% for the Inside pitch, from 33% to 100% for the Middle pitch, and from 24% to 100% for the Outside pitch.

Figure 4 presents the horizontal, anterior/posterior, and vertical GRF on the pivot-side under each condition. In the horizontal component, the BRC condition showed significantly lower values than the BC condition from 35% to 100% for the Inside pitch, from 49% to 100% for the Middle pitch, and from 44% to 100% for the Outside pitch. In the anterior/posterior component, the BRC condition exhibited significantly higher values than the BC condition from 99% to 100% for the Inside pitch, from 80% to 100% for the Middle pitch, and from 4% to 12% and from 86% to 100% for the Outside pitch. In the vertical component, the BRC condition showed significantly higher values than the BC condition from 77% to 100% for the Middle pitch and from 47% to 100% for the Outside pitch.

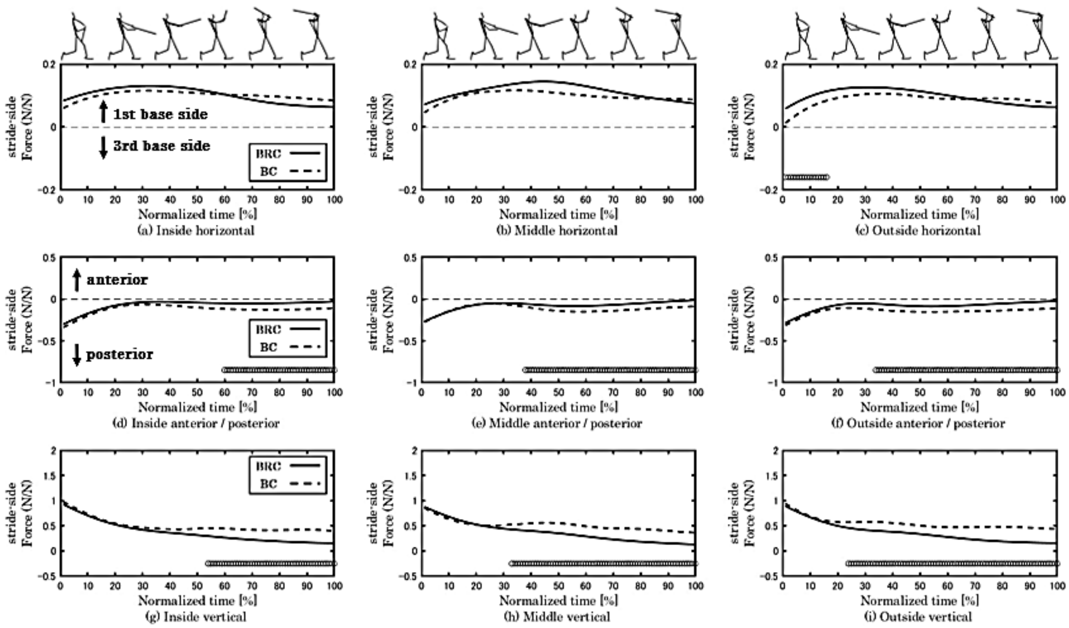


Figure 3 Ground reaction force values for each component at stride-side under each condition: (a) X-axis component in Inside, (b) X-axis component in Middle, (c) X-axis component in Outside, (d) Y-axis component in Inside, (e) Y-axis component in Middle, (f) Y-axis component in Outside, (g) Z-axis component in Inside, (h) Z-axis component in Middle, and (i) Z-axis component in Outside.

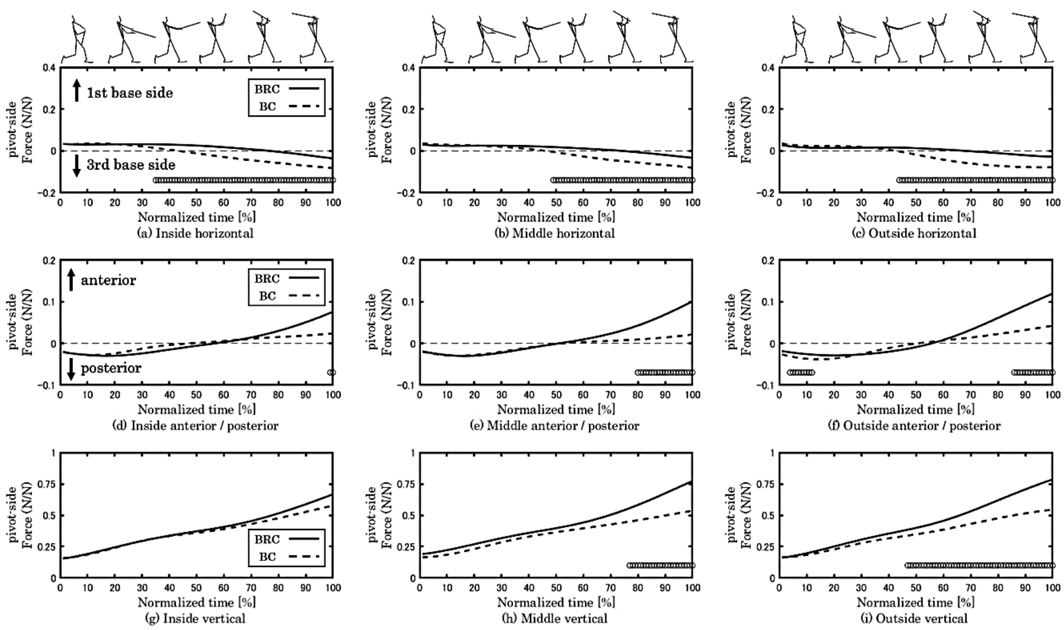


Figure 4 Ground reaction force values for each component at pivot-side under each condition: (a) X-axis component in Inside, (b) X-axis component in Middle, (c) X-axis component in Outside, (d) Y-axis component in Inside, (e) Y-axis component in Middle, (f) Y-axis component in Outside, (g) Z-axis component in Inside, (h) Z-axis component in Middle, and (i) Z-axis component in Outside.

Angle of shoulder and hip rotation
Figure 5 shows the shoulder rotation angle (a, b, c) and hip rotation angle (d, e, f) under each condition. Regarding the shoulder rotation angle, the BRC condition showed significantly lower values compared to the BC condition from 42% to 73% of the FT Phase for the Inside pitch, and from 40% to 95% for the Outside pitch. As for the hip rotation angle, the BRC condition showed significantly lower values than the BC condition from 68% to 100% for the Middle pitch.

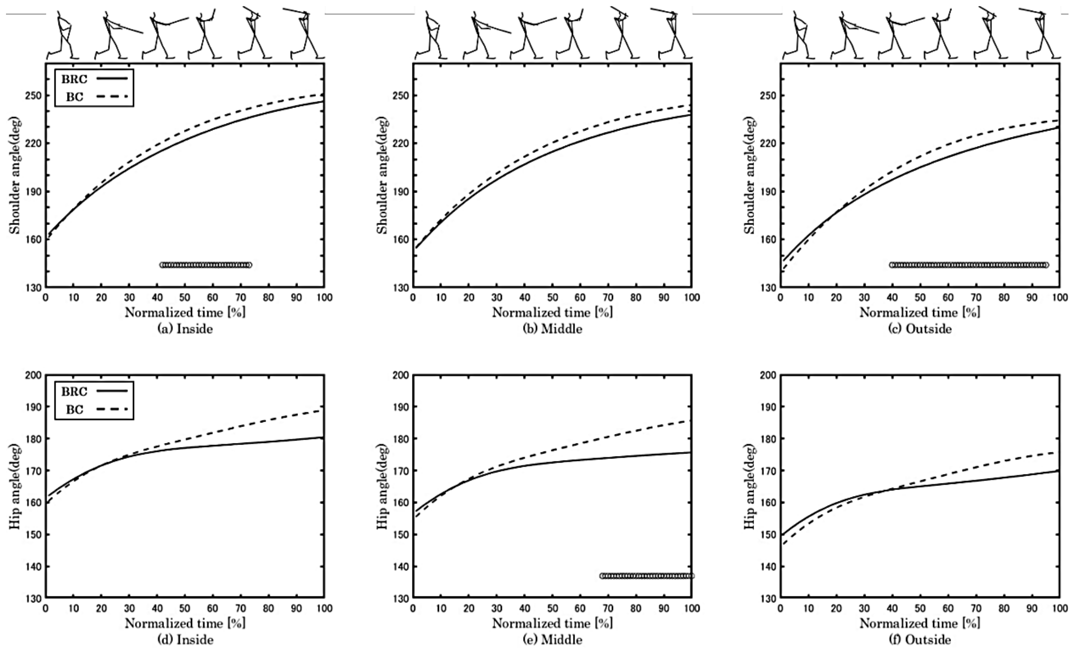


Figure 5 Time series data of angular velocity of shoulder and hip under each condition: (a) Inside shoulder angular velocity, (b) Middle shoulder angular velocity, (c) Outside shoulder angular velocity, (d) Inside hip angular velocity, (e) Middle hip angular velocity, and (f) Outside hip angular velocity.

***Angular velocity of shoulder and hip rotation***
Figure 6 shows the angular velocity of shoulder rotation (a, b, c) and hip rotation (d, e, f) under each condition. For the shoulder rotation angular velocity, the BRC condition showed significantly lower values than the BC condition from 69% to 100% of the FT Phase for the Outside pitch. Regarding the hip rotation angular velocity, the BRC condition showed significantly lower values compared to the BC condition from 44% to 86% for the Inside pitch, from 32% to 100% for the Middle pitch, and from 43% to 70% for the Outside pitch.

***Displacement of the whole-body centre of mass***
Table 1 shows the centre of mass (CM) displacement during the FT Phase. For the Inside pitch, no significant difference was observed between the BRC and BC conditions (n.s.). However, for the Middle pitch, the CM displacement was significantly greater in the BRC condition compared to the BC condition ($p < .01$). Similarly, for the Outside pitch, the BRC condition showed a significantly greater displacement than the BC condition ($p < .05$). Additionally, Figure 7 presents the averaged whole-body centre of mass trajectories (CM trajectories). In these figures, the initial CM position at the moment of impact was standardized across both BRC and BC conditions. Furthermore, Table 2 shows the whole-body centre of mass velocity for each course in the BRC and BC conditions, and no significant differences were observed.

Table 1. Whole-body centre of mass displacement for each course in BRC and BC.

| | Whole-body centre of mass displacement | | |
|---|---|---|---|
| | **BRC** | **BC** | ***p*-Value** |
| Inside (m) | 0.073 ± 0.022 | 0.066 ± 0.030 | .331 ns |
| Middle (m) | 0.081 ± 0.024 | 0.060 ± 0.017 | .002 ** |
| Outside (m) | 0.084 ± 0.025 | 0.065 ± 0.017 | .039 * |

*Note. *p < .05; **p < .01; ns. = not significant.*

Table 2. Whole-body centre of mass velocity for each course in BRC and BC.

| | Whole-body centre of mass velocity | | |
|---|---|---|---|
| | **BRC** | **BC** | ***p*-Value** |
| Inside (m/s) | 0.550 ± 0.076 | 0.537 ± 0.078 | .399 ns |
| Middle (m/s) | 0.533 ± 0.086 | 0.510 ± 0.077 | .197 ns |
| Outside (m/s) | 0.488 ± 0.070 | 0.466 ± 0.075 | .201 ns |

*Note. ns. = not significant.*

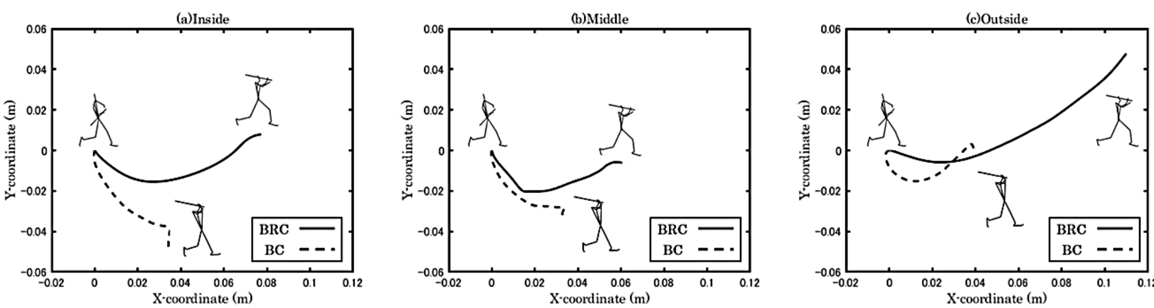


Figure 7 Whole-body centre of mass trajectory: (a) Inside trajectory, (b) Middle trajectory, (c) Outside trajectory, (d) Inside velocity, (e) Middle velocity, and (f) Outside velocity.

## DISCUSSION

This study aimed to compare the body movements of BRC and BC during the FT Phase of the middle phase, with a focus on right-handed batters. Based on the results, numerous differences were observed between the two conditions in terms of ground reaction forces, body movements, and CM displacement. The following section discusses these aspects from the perspective of the respective calculated parameters of BRC and BC movements.

### *Ground reaction force*

*Resultant ground reaction force*

For all pitch locations (Inside, Middle, and Outside), the GRF on the stride side decreased from impact to the end of the swing, with BRC showing lower values than BC during this period. In contrast, on the pivot side, the GRF increased during the same period, with BRC exhibiting higher values than BC. These results on both the stride and pivot sides suggest that, during the FT Phase, a transition from batting to base running is already occurring in preparation for running to first base. Therefore, the following discussion considers the role of each component—horizontal, anterior/posterior, and vertical GRF—in greater detail.

*Horizontal GRF*

During the batting motion from swing initiation to impact, it has been reported that, after the stride-side foot makes contact with the ground, the body's movement shifts from translational to rotational motion (Hirano and Machinaga, 1990). Additionally, it has been noted that GRF values in the X-axis are larger than those in the Y-axis (Yanai, 2007 ; Ae et al., 2017 ; Ae et al., 2018). These findings suggest that the X-axis primarily contributes to body rotation. Ae et al. (2017) also reported that the group with higher peak moments around the vertical axis showed significantly greater X-axis GRF values than the lower-performing group.

Prior to impact, the GRF vectors generally point toward the third base side for the stride-side and toward the first base side for the pivot-side. However, in the present study, after impact in the BRC condition, the direction of the GRF vectors reversed for all pitch locations: the stride-side pointed toward the first base side and the pivot-side toward the third base side.

As shown in Figure 3, in the stride-side horizontal GRF for the Outside pitch (c), there was a significantly greater value in BRC compared to BC. Due to the characteristics of the Outside pitch, rotation of the trunk toward the third base side after impact may be more restricted than in the Inside or Middle pitches. This is also supported by the data shown in Figure 5 (c) Shoulder angle for Outside, where leftward rotation was generally suppressed throughout the movement compared to the other pitch locations (a, b). This reduced leftward trunk rotation suggests that initiating the sprint to first base may be easier after hitting an Outside pitch compared to the other pitch types. Thus, the significant difference observed in horizontal GRF in the Outside condition may reflect this tendency.

However, since the time interval with a significant difference was brief and occurred shortly after impact, further research is needed to determine whether this difference offers an actual advantage for base running.

In Figure 4, for the pivot-side horizontal GRF (a, b, c), BRC showed significantly lower GRF values toward the third base side compared to BC across all pitch locations. This GRF directed toward third base could be a disadvantage when transitioning into the sprint toward first base. In sprinting events, it is considered important during the acceleration phase to direct ground reaction force vectors forward (Morin et al., 2011), minimizing backward-directed GRF components while maximizing forward-directed ones. Therefore, it is likely that the participants in this study also suppressed GRF toward the third base side more in BRC than in BC in preparation for the post-impact sprint.

In the coordinate system used for GRF in this study, the Y-axis represents the pitcher's direction, the Z-axis represents the vertical direction, and the X-axis is defined as the cross product of the Y- and Z-axis. Hence, in this study, along with differences observed in the Y-axis (discussed later), significant differences were also observed in the X-axis due to the transition toward running to first base.

*Anterior / posterior GRF*

In all pitch locations shown in Figure 3, stride-side anterior/posterior GRF (d, e, f), the posterior GRF values for BRC were lower than those for BC. Conversely, in Figure 4, pivot-side anterior/posterior GRF (d, e, f), the anterior GRF values for BRC were higher than those for BC across all pitch locations. Similar to the findings in horizontal GRF, the reduction of posterior GRF on the stride-side and the increase of anterior GRF on the pivot-side are thought to be associated with the transition to base running toward first base.

For the pivot-side in Figure 4 (d) Inside anterior/posterior, unlike the Middle and Outside pitches (e, f), which showed significantly higher anterior GRF values in BRC than in BC from approximately 80% of the phase onward, the Inside condition showed a significant difference only between 99% and 100%. The increase in anterior GRF on the pivot-side in BRC is believed to reflect the body's translational motion in preparation for the run to first base. However, the fact that the significant difference in the Inside condition appeared only over a very short interval suggests that sufficient translational movement, which is necessary for initiating the sprint, may not have been achieved in that condition.

This result may also be due to pitch location. Since the Inside pitch typically induces greater leftward trunk rotation toward the third base side compared to other pitch locations, it is possible that rotational motion continued beyond impact during the FT Phase, making it more difficult to initiate translational motion. Whether this characteristic of the Inside pitch is irreversible in a batter's swing motion remains unclear. However, given that anterior GRF increases were achieved in other pitch conditions, it is likely that technique adjustments could also enable anterior GRF gains in the Inside condition.

Although there is a large body of research on anterior/posterior GRF in sprinting (Mero et al., 1983 ; Nagahara et al., 2021), few studies have examined the intermediate phase from hitting to base running in baseball. Therefore, the findings regarding the characteristics of horizontal and anterior/posterior GRF on the XY plane may provide new insights for both research and coaching applications.

*Vertical GRF*

In all pitch locations shown in Figure 3, stride-side vertical GRF (g, h, i) was significantly lower in BRC compared to BC. Conversely, in all pitch locations in Figure 4, pivot-side vertical GRF (g, h, i) was significantly higher in BRC than in BC.

These significant differences in vertical GRF correspond to the same time intervals where significant differences were observed in the Resultant GRF for the stride-side (a, b, c) and pivot-side (d, e, f) in Figure 2. Given the magnitude of vertical GRF values, they greatly influence the magnitude of the resultant GRF. Therefore, the results of this study indicate that in the BRC condition, the stride-side foot applied less force into the ground, while the pivot-side foot applied more force compared to the BC condition.

Although these results likely reflect the transition to base running toward first base, this pattern may not necessarily contribute to a shorter time in initiating the sprint to first. Ohyama and Maeda (in press) reported that during the phase from impact to leaving the batter's box, no correlation was observed between the peak value of GRF and motion time, but a significant correlation was found with the time from impact to reaching the GRF peak. This finding highlights the importance of "*quick postural transition*" rather than "*strong initial force*." In light of this, the vertical GRF characteristics obtained in the present study suggest that, in the BRC condition, athletes are already engaging in base running during the FT Phase, and the vertical GRF in this phase may contribute to a quicker sprint initiation.

A previous study involving MLB players reported that the time to reach first base was most influenced by the acceleration phase within the 13.7-meter (45-foot) distance from home plate to the 3-foot line (Coleman and William, 2012). Therefore, post-impact GRF during the initial phase of the sprint likely has a critical effect on acceleration. Based on the present findings, further research is warranted to clarify how GRF characteristics during this transition phase influence base running performance.

***Angle of shoulder and hip rotation and angular velocity of rotation***

Regarding shoulder and hip rotation angles in Figure 5, this study calculated the angle relative to the X-axis. A larger rotation angle thus indicates greater leftward rotation toward third base. In the upper panels of Figure 5, which show shoulder rotation angles, no significant differences were found between conditions in (b) Middle. However, in (a) Inside and (c) Outside, there were intervals where BRC showed significantly smaller rotation angles compared to BC. In the lower panels of Figure 5, which show hip rotation angles, (e) Middle showed intervals where BRC also had smaller rotation angles than BC. Although no significant differences were observed in the other conditions, there was a general tendency toward smaller rotation angles in BRC during the latter half of the analysis period.

In Figure 6, the upper panels show shoulder rotation angular velocity. In (c) Outside, BRC displayed significantly lower angular velocity compared to BC. In the lower panels of Figure 6, which depict hip angular velocity, BRC demonstrated significantly lower values across all pitch locations—(d) Inside, (e) Middle, and (f) Outside—compared to BC.

Murase et al. (2016) reported that in complex motor skills such as catching followed by throwing, shoulder and hip rotation angles tend to rotate toward the pitcher's direction more than in simple skills, and that the final phase of catching serves as a transitional movement preparing for throwing. In their case, a larger rotation angle during catching likely facilitated a smoother transition into the subsequent throwing phase. In contrast, in the present study, batters transition from leftward rotation during the swing to rightward rotation as they shift into base running after the swing. This transition requires a reversal of the rotational motion. Therefore, the participants likely needed to reduce the rotational angles of the shoulder and hip and, in turn, adjusted by reducing the angular velocity of these segments.

These findings support previous research (Murase et al., 2016 ; Marteniuk et al., 1987), which suggests that the final phase of a preceding movement in complex motor skills is modified in accordance with the goal of the subsequent action.

***Whole-body centre of mass displacement and whole-body centre of mass velocity***

Regarding CM displacement shown in Table 1, no significant difference was found between BRC and BC for the Inside pitch. However, in the Middle and Outside pitches, BRC showed significantly greater CM displacement compared to BC. In contrast, as shown in Table 2, no significant differences in CM velocity were observed between BRC and BC.

All CM displacement values listed in Table 1 were notably smaller than the Y-axis CM displacement reported by Takagi et al. (2008), measured from the point of maximal backward movement toward the catcher to just before bat-ball contact. However, the significantly greater CM displacement in BRC compared to BC in the Inside and Outside pitches suggests that a transition toward base running may already be occurring during the FT Phase.

Furthermore, the CM trajectory shown in Figure 7 indicates that BRC tended to shift more along the X-coordinate (m) than BC, which may also reflect the initiation of movement toward first base. Although there were no significant differences in CM velocity between BRC and BC during the FT Phase, it was evident that players engaged in body movements to transition toward base running even with such minimal CM velocity.

## CONCLUSIONS

This study focused on the FT Phase of the transitional period in right-handed batters and aimed to compare body movements between BRC (batting with the intention to run) and BC (batting only).

1. In Resultant GRF, BRC showed significantly lower values than BC on the stride-side for all pitch locations (a, b, c) Inside, Middle, and Outside. Conversely, on the pivot-side, BRC showed significantly higher values than BC in (e, f) Middle and Outside.

2. In Horizontal GRF, on the stride-side, BRC displayed significantly higher values than BC in the Outside pitch. On the pivot-side, significant increases in BRC compared to BC were observed for all pitch locations—Inside, Middle, and Outside.
3. In Anterior/Posterior GRF, on the stride-side, BRC showed significantly lower values than BC for all pitch locations. In contrast, on the pivot-side, BRC displayed significantly higher values than BC across all pitch locations.
4. In Vertical GRF, BRC exhibited significantly lower values than BC for all pitch locations on the stride-side, while showing significantly higher values than BC on the pivot-side for all pitches.
5. For shoulder rotation angle, significant differences were observed in (a, c) Inside and Outside, where BRC showed lower angles than BC. For hip rotation angle, a significant difference was found in (e) Middle, with BRC again showing lower angles. Shoulder rotation angular velocity in (c) Outside and hip rotation angular velocity across all pitch locations were significantly lower in BRC compared to BC.
6. In CM displacement, BRC showed significantly greater displacement than BC in the Middle pitch ($p < .01$) and also in the Outside pitch ($p < .05$).

## AUTHOR CONTRIBUTIONS

Kanzi Ohyama was responsible for the conceptualization of the study, experimental design, data collection, data analysis and interpretation, and writing of the original draft. Akira Maeda contributed through supervision and project administration, provided methodological guidance, assisted in data interpretation, critically reviewed and edited the manuscript, and handled correspondence with the journal.

## SUPPORTING AGENCIES

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## DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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