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Start Technique and Acceleration-Phase Kinematics Associated With 100-m Sprint Performance in Physical Education Students of Universitas Negeri Makassar

Mohammad Dika Raswadi[1*]

[1] Department of Physical Education, Health and Recreation, Faculty of Sport and Health Sciences, Universitas Negeri Makassar, Makassar, Indonesia

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Corresponding author:
Mohammad Dika Raswadi

E-mail address:
Mohammad23dika@unm.ac.id

ABSTRACT

Introduction. The start and initial acceleration are important in short sprints, but evidence from physical education students is limited. This study examined associations of start-technique and acceleration-phase variables with 100-m sprint performance among students of the Physical Education, Health and Recreation Study Program (PJKR), Faculty of Sport and Health Sciences, Universitas Negeri Makassar. **Methods.** In a cross-sectional correlational study of 30 students, reaction time, push projection angle, initial trunk inclination, 10-m and 20-m split times, step length, step frequency, ground contact time, and 100-m time were recorded. Pearson and Spearman correlations with Holm adjustment and hierarchical multiple regression were applied ($\alpha = .05$). **Results.** Mean 100-m time was 11.48 ± 0.52 s. Reaction time ($r = .84$) and the 10-m ($r = .90$) and 20-m ($r = .92$) split times correlated with 100-m time, whereas projection angle, trunk inclination, and ground contact time did not. Step length ($r = -.32$; $\rho = -.39$) and step frequency ($r = -.46$; $\rho = -.34$) showed inconsistent associations that did not survive adjustment. Start variables explained 72.5% of the variance; adding step length, step frequency, and contact time did not significantly increase it ($R^2 = .796$; $\Delta R^2 = .071$, $p = .073$). In the final model, reaction time was the only robust predictor ($\beta = .72$, $p < .001$). **Conclusion.** Reaction time and early split times were the strongest correlates of 100-m time in this sample. Because the design was cross-sectional, the sample was small and pooled both sexes, and split-time resolution was limited, these associations do not show that training any single variable would improve performance.

1. Introduction

The 100-m sprint is commonly divided into acceleration, maximum-velocity, and deceleration phases (Seidl et al., 2021), and the performance of the block start and the first steps has a direct influence on the overall race time (Valamatos et al., 2022). Walker et al. (2021) described the start and initial acceleration phase as being of key importance in short sprints and reported clear relationships between first-contact horizontal power and 10-m time among world-class sprinters. Reviews of the sprint start have synthesised the kinematic and kinetic determinants of block-phase performance (Bezodis et al., 2019), and power and technique are considered key underlying determinants of 100-m performance (Haugen et al., 2019).

Even so, the contribution of individual start variables remains debated. In a comparison of high-level and medium-level male sprinters, reaction time and starting-block inclination did not differ between groups (Li et al., 2024). In World Championships finalists, the association between reaction time and 100-m results was low and appeared in men only (Pavlović, 2021), whereas other work, including studies of 60-m and hurdle events that share the block start, continues to examine reaction time as a determinant of sprint results (Gürses & Kamiş, 2018; Matić & Mrdaković, 2023; Zhang et al., 2021). Start kinematics also differ with sex and, to a larger degree, with performance level (Ciacci et al., 2017), and male national-level sprinters show higher force and power capacities than female sprinters (Mirkov et al., 2020). Findings therefore cannot simply be transferred between populations.

After block exit, acceleration-phase kinematics add further explanatory variables. Morin et al. (2012) found that step frequency and contact time, but not step length, were related to 100-m performance.

Faster trials within a single session were accompanied by higher step frequency and shorter support time at all steps (Nagahara et al., 2018). In soccer players, whose sprint training background differs from that of sprinters, longer steps in the first phase and higher step frequency later were linked with effective acceleration (Murata et al., 2018). Sub-elite male sprinters showed higher step rates and shorter contact times than recreational sprinters during acceleration (Stavridis et al., 2022). At maximal speed, faster sprinters used shorter contact times, longer steps, and faster step rates (Paradisis et al., 2019), and the kinetic demands of sprinting shift across the acceleration phase (Colyer et al., 2018; Jiménez-Reyes et al., 2024).

Evidence from students is comparatively scarce. Physical education students differed from advanced sprinters in start reaction time, although reaction time alone appeared to have a limited influence on start effectiveness (Borysiuk et al., 2018). In active students, acceleration performance was related mainly to running speed and stride frequency (Maćkała et al., 2015). Students of physical education teacher-education programmes are a relevant group because they are expected to demonstrate and teach sprint technique, yet their training status is heterogeneous. This study therefore aimed to examine the associations of start-technique and acceleration-phase variables with 100-m sprint performance among PJKR students of the Faculty of Sport and Health Sciences, Universitas Negeri Makassar (FIKK UNM). We expected that shorter reaction time, faster early split times, longer steps, higher step frequency, shorter contact times, and more favourable start angles would accompany faster 100-m times. Given the modest sample, all analyses were interpreted as exploratory.

2. Methods

2.1. Study Design and Participants

This study employed a quantitative cross-sectional correlational design to examine the relationships between sprint start technique, acceleration-phase kinematic characteristics, and 100-m sprint performance among undergraduate students. The participants were 30 students enrolled in the PJKR Study Program, Faculty of Sport and Health Sciences (FIKK), Universitas Negeri Makassar (UNM), Indonesia. Each participant was assigned an anonymous identification code

The participants were 30 undergraduate students from the Physical Education, Health, and Recreation (PJKR) Study Program, Faculty of Sports and Health Sciences, Universitas Negeri Makassar, Indonesia. Their mean age was 20.3 years, while the mean body height and body mass were 168.8 ± 5.3 cm and 62.3 ± 8.5 kg, respectively. Participants were recruited using purposive sampling based on predefined eligibility criteria and their ability to complete the maximal-effort 100-m sprint testing protocol. No a priori sample-size calculation was reported. Given the sample size (n = 30), the findings should be interpreted with consideration of the limited statistical power for detecting small-to-moderate associations and the potential risk of overfitting in multivariable regression models involving multiple predictors.

The inclusion criteria were: (1) active undergraduate students enrolled in the PJKR study program; (2) aged 18–23 years; (3) physically capable of performing maximal-effort sprinting; (4) having no musculoskeletal injuries during the preceding three months; and (5) providing written informed consent before participation. Students with current musculoskeletal injuries, medical conditions that contraindicated maximal sprint exercise, or incomplete primary measurement data were excluded from the analysis.

2.2. Variables and Measurements

The independent variables consisted of biomechanical characteristics of the starting technique and kinematic characteristics of the acceleration phase. The dependent variable was 100-m sprint performance, expressed as total completion time in seconds.

2.2.1. Start Technique Variables

Three biomechanical variables were evaluated during the starting phase:

1. **Reaction time (s):** the interval between the starting signal and the first movement response, determined from video synchronized with the starting signal.
2. **Push projection angle (°):** defined as the angle of the resultant body projection during the initial push-off from the starting position. The angle was determined relative to the horizontal axis using calibrated video recordings and standardized anatomical landmarks.
3. **Initial trunk inclination (°):** defined as the angle of the trunk relative to the horizontal axis at the beginning of the acceleration phase. The angle was determined from the alignment of the shoulder and hip anatomical landmarks.

2.2.2. Acceleration-Phase Variables

The acceleration phase was evaluated over the initial 20 m using: (1) 10-m split time (s) and (2) 20-m split time (s), the cumulative times from the starting signal to each mark; (3) mean step length (m), the average horizontal distance per step within the first 20 m; (4) step frequency (Hz), the number of steps per second within the same zone; and (5) ground contact time (s), the mean duration of foot contact across ground-support phases. Step length, step frequency, and ground contact time were extracted from high-speed video by frame-by-frame analysis.

2.2.3. 100-m Sprint Performance

The primary performance outcome was the total time required to complete the 100-m sprint, measured in seconds. Timing was initiated using the standardized starting signal and stopped when the participant's torso crossed the vertical plane of the finish line.

2.2.4. Measurement Equipment and Video Analysis

Sprint performance was measured using a dual-beam electronic timing system with photocell gates at the 10-m, 20-m, and 100-m marks, configured with a resolution of 0.001 s and synchronized with the starting signal.

High-speed video was recorded at 240 frames per second with a minimum resolution of 1920 × 1080 pixels, using a tripod-mounted camera positioned perpendicular to the running direction. Camera height and distance were standardized across participants to reduce perspective distortion.

Video recordings were analyzed using Kinovea software (version 0.9.5). The analysis involved identifying relevant movement events, measuring trunk inclination and push projection angles, and determining step length, step frequency, and ground contact time. Spatial measurements were calibrated using a reference marker of known length positioned within the camera's field of view and aligned with the running plane.

Temporal measurements were obtained through frame-by-frame analysis, with each frame corresponding to approximately 0.0042 s at 240 fps. Step frequency was calculated as the number of steps divided by the corresponding elapsed time, while mean step length was calculated as the total horizontal distance covered divided by the number of steps within the designated acceleration zone.

2.3. Procedure and Ethics

Data collection was conducted on a 100-m athletics track at Universitas Negeri Makassar, Indonesia.

Before testing, participants received an explanation of the study objectives, procedures, and potential physical demands. Anthropometric measurements, including body height and body mass, were recorded before the sprint test.

Each participant completed a standardized warm-up consisting of 10–15 minutes of light aerobic activity, dynamic stretching, mobility exercises, running drills, and progressive acceleration sprints. Following the warm-up, participants were allowed an adequate recovery period before performing the maximal-effort sprint test.

All participants performed the 100-m sprint from starting blocks using a crouch start, initiated by an audible signal, and were instructed to run with maximal effort throughout.

2.4. Statistical Analysis

Analyses were carried out in Python 3 (SciPy and statsmodels) with a two-tailed significance level of .05. Descriptive statistics are presented as mean ± standard deviation, and normality was checked with the Shapiro–Wilk test. Because the split times and 100-m time departed from normality, Spearman's ρ and Pearson's r (with 95% confidence intervals from the Fisher z transformation) are reported with equal weight, and an association was regarded as consistent only when both supported it. p values for the eight correlations were adjusted separately for each coefficient using the Holm procedure. Magnitudes were interpreted using the thresholds of Hopkins et al. (2009). Hierarchical multiple regression estimated combined contributions, with reaction time, projection angle, and trunk inclination entered in Block 1 and step length, step frequency, and ground contact time added in Block 2. Split times were not entered because they contain the reaction-time component and are highly collinear with it. Assumptions were checked with variance inflation factors, the Shapiro–Wilk test on residuals, the Breusch–Pagan test, and Cook's distance. Sensitivity was examined using heteroscedasticity-robust (HC3) standard errors and 5,000 bootstrap resamples. Cohen's f^2 was calculated as $R^2/(1 - R^2)$.

3. Results

3.1. Descriptive Statistics

Table 1 presents the descriptive statistics. Participants ran 100 m in 11.48 ± 0.52 s (range 10.90–12.31 s). Reaction time, projection angle, trunk inclination, step length, step frequency, and contact time showed no significant departure from normality (Shapiro–Wilk $p > .05$), whereas the 10-m split, 20-m split, and 100-m times did ($p \leq .009$). The 10-m split times clustered at the two extremes of the range: 11 participants recorded 1.88 s and 7 recorded 2.28 s (18 of 30).

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Table 1. Descriptive statistics of anthropometric, start-technique, acceleration-phase, and performance variables (*n* = 30)

Variable	M ± SD	Min–Max	Shapiro–Wilk *p*
Participant characteristics			
Age (years)	20.3 ± 1.4	18-23	0.109
Sex, male / female (*n*)	18/12	—	—
Height (cm)	168.8 ± 5.3	157.0–182.2	.906
Body mass (kg)	62.3 ± 8.5	46.6–82.0	.376
Start technique			
Reaction time (s)	0.201 ± 0.026	0.155–0.268	.806
Push projection angle (°)	42.4 ± 4.2	33.4–52.0	.988
Initial trunk inclination (°)	46.7 ± 4.5	35.5–56.0	.877
Acceleration phase			
10-m split time (s)	2.03 ± 0.17	1.88–2.28	<.001
20-m split time (s)	3.52 ± 0.17	3.26–3.80	.009
Step length (m)	1.95 ± 0.11	1.71–2.12	.156
Step frequency (Hz)	4.11 ± 0.26	3.65–4.61	.513
Ground contact time (s)	0.119 ± 0.010	0.095–0.143	.997
Performance			
100-m time (s)	11.48 ± 0.52	10.90–12.31	<.001

Note. *M* = mean; *SD* = standard deviation. Shapiro–Wilk $p < .05$ indicates departure from normality; for those variables, interpret the mean with the range.

3.2. Associations With 100-m Time

Reaction time was strongly associated with 100-m time ($r = .84$, 95% CI [.70, .92]; $\rho = .88$; Figure 1a), as were the 10-m split ($r = .90$; $\rho = .87$; Figure 1b) and 20-m split ($r = .92$; $\rho = .82$) times; all remained significant after Holm adjustment ($p < .001$; Table 2). Push projection angle and initial trunk inclination showed no significant association. Results for the step variables depended on the method: step frequency was significant with Pearson's *r* ($r = -.46$, $p = .011$) but not Spearman's ρ ($\rho = -.34$, $p = .063$), and the reverse was true for step length ($r = -.32$, $p = .089$; $\rho = -.39$, $p = .031$). Neither remained significant after adjustment. Ground contact time was not significantly associated with 100-m time ($r = .27$, $p = .149$). The time between 10 m and 20 m (1.49 ± 0.06 s) was unrelated to 100-m time ($r = -.04$, $p = .835$).

Table 2. Associations of start-technique and acceleration-phase variables with 100-m time (*n* = 30)

Variable	Pearson r [95% CI]	p	pH	ρ	p	pH	Magnitude (r / ρ)
Start technique							
Reaction time	.84 [.70, .92]	<.001	<.001	.88	<.001	<.001	Very large / very large
Push projection angle	.22 [-.15, .54]	.243	.486	.30	.104	.312	Small / moderate
Initial trunk inclination	-.04 [-.40, .32]	.817	.817	.06	.751	.751	Trivial / trivial
Acceleration phase							
10-m split time	.90 [.81, .95]	<.001	<.001	.87	<.001	<.001	Nearly perfect / very large
20-m split time	.92 [.83, .96]	<.001	<.001	.82	<.001	<.001	Nearly perfect / very large
Step length	-.32 [-.61, .05]	.089	.356	-.39	.031	.155	Moderate / moderate
Step frequency	-.46 [-.70, -.12]	.011	.055	-.34	.063	.252	Moderate / moderate
Ground contact time	.27 [-.10, .57]	.149	.447	.26	.169	.338	Small / small

Note. *p*H = Holm-adjusted *p*. Magnitude: |*r*| / |ρ| (Hopkins et al., 2009).

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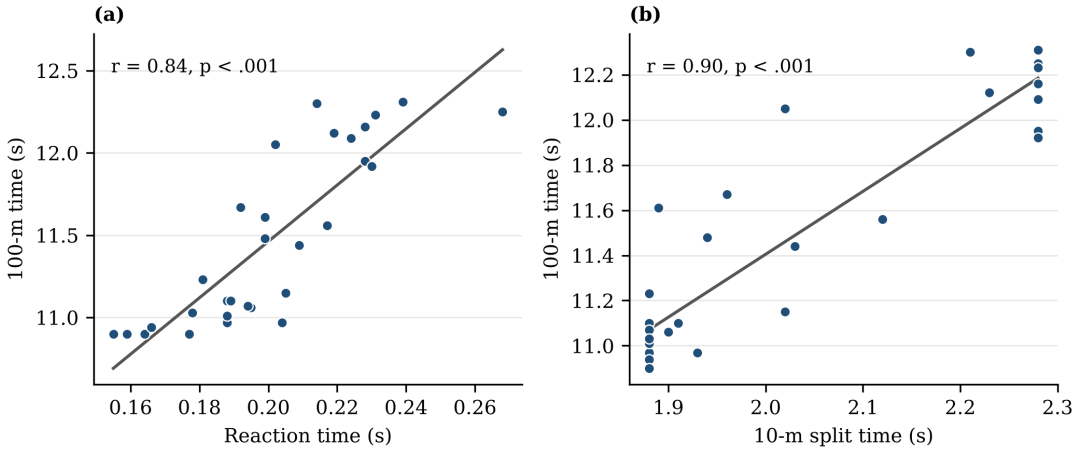

Figure 1. Association of (a) reaction time and (b) 10-m split time with 100-m time

Note. Lines are least-squares fits; *r* = Pearson correlation. Points in panel (b) overlap because many participants share identical split times.

3.3. Regression Models

Block 1 (start technique) was significant, $F(3, 26) = 22.86$, $p < .001$, $R^2 = .725$ (adjusted $R^2 = .693$); within it, only reaction time contributed (β = .85, $p < .001$), while projection angle (β = .03, $p = .801$) and trunk inclination (β = -.10, $p = .323$) did not. Reaction time alone corresponds to an R^2 of about .71 (the square of $r = .84$), so the Block 1 result is almost entirely attributable to it. The full model gave $R^2 = .796$ (adjusted $R^2 = .742$), $F(6, 23) = 14.92$, $p < .001$, $f^2 = 3.89$, but the increment over Block 1 was not significant ($\Delta R^2 = .071$, $F(3, 23) = 2.65$, $p = .073$); the more parsimonious start-technique model is therefore not clearly improved by the step variables. In the full model (Table 3), reaction time was the dominant predictor (β = .72). Step length ($p = .040$) and step frequency ($p = .037$) had negative coefficients, but these were not robust: HC3 *p* values were .092 and .070, and the bootstrap 95% CIs were [-2.27, -0.05] and [-0.95, 0.02], respectively. Assumption checks showed maximum VIF = 1.37, residual Shapiro–Wilk $p = .303$, Breusch–Pagan $p = .284$, and maximum Cook's $D = 0.16$.

Table 3. Hierarchical multiple regression predicting 100-m time (final model, Block 2)

Predictor	*B*	*SE*	95% CI	*β*	*p*	*p* (HC3)
Constant	12.510	1.734	[8.922, 16.097]		<.001	<.001
Reaction time (s)	14.517	2.238	[9.886, 19.147]	.715	<.001	<.001
Push projection angle (°)	0.005	0.013	[-0.021, 0.031]	.041	.695	.718
Initial trunk inclination (°)	-0.003	0.012	[-0.027, 0.021]	-.025	.803	.819
Step length (m)	-1.048	0.483	[-2.047, -0.050]	-.227	.040	.092
Step frequency (Hz)	-0.479	0.216	[-0.927, -0.031]	-.241	.037	.070
Ground contact time (s)	-0.105	5.215	[-10.894, 10.683]	-.002	.984	.986

Note. Block 1 (reaction time, projection angle, trunk inclination): $R^2 = .725$, adjusted $R^2 = .693$. Block 2 (all six predictors): $R^2 = .796$, adjusted $R^2 = .742$, $\Delta R^2 = .071$, $p = .073$. *B* = unstandardized coefficient; *β* = standardized coefficient; HC3 = heteroscedasticity-robust standard errors.

4. Discussion

In this sample of PJKR students, reaction time and the early split times were the strongest correlates of 100-m performance, while push projection angle, trunk inclination, and contact time showed no significant association. The association for reaction time ($r = .84$) is far larger than the low association reported for World Championships finalists (Pavlović, 2021) and contrasts with the absence of reaction-time differences between high-level and medium-level sprinters (Li et al., 2024). It is also large in practical terms. The regression slope implies that a reaction time 1 *SD* slower (0.026 s) accompanied a

100-m time about 0.38 s slower, roughly 15 times the reaction-time difference itself. The delay at the start therefore cannot by itself account for the association. Part–whole overlap, because 100-m time is measured from the starting signal, is also an unlikely full explanation: based on the reported standard deviations and correlation, reaction time would still correlate about .82 with the remainder of the race time. More plausible explanations are that reaction time acted as a marker of sex, training status, or general sprint ability, or that measurement or data artefacts were present. The present analysis cannot separate these possibilities, and the finding should not be read as a causal start effect.

The two angular start variables were unrelated to 100-m time. An angle describes the direction of the push or the posture adopted, not the force and impulse produced; horizontal external power has been proposed as the criterion of early-sprint performance for this reason (Walker et al., 2021). Without force data, this study cannot tell whether students with similar angles differed in the force they applied.

Results for the acceleration kinematics agreed only partly with earlier work. Morin et al. (2012) linked step frequency and contact time, but not step length, to 100-m performance. In the present study, step frequency was significant only with Pearson's *r*, step length only with Spearman's ρ and the non-robust regression coefficient, and contact time was not significant. The direction for step frequency is consistent with findings in sprinters and active students (Maćkała et al., 2015; Nagahara et al., 2018; Stavridis et al., 2022), but none of the step results survived multiplicity adjustment, so they neither confirm nor refute the earlier pattern. Differences in population, measurement zone (the first 20 m here), narrow variation in contact time (0.095–0.143 s), and limited power may contribute. The lack of association for the 10–20 m interval may suggest that differences were already present within the first 10 m, which include reaction time, and is compatible with determinants that vary across acceleration (Colyer et al., 2018; Jiménez-Reyes et al., 2024). However, the clustered 10-m times make this interpretation weak.

For practice, these results do not justify prescribing a particular training emphasis or a single "ideal" start angle. Start and early-acceleration drills remain reasonable parts of sprint instruction, where power and technique are developed together (Haugen et al., 2019), but whether improving reaction time or step frequency shortens 100-m time in this population must be tested in intervention studies.

4.1. Strengths and Limitations

Start and acceleration variables were measured in the same trials, and the regression results were checked with alternative estimators. The limitations, in order of importance, are: (1) male and female students were pooled without sex-stratified or sex-adjusted analyses, so between-sex differences may have inflated the correlations; (2) training status and wind were not controlled statistically; (3) the sample was small (n = 30) for eight correlations and a six-predictor model, with no cross-validation; (4) 10-m split times clustered at 1.88 s and 2.28 s, raising concerns about timing resolution that affect the split-time results in particular; (5) reaction time was derived from video rather than block force sensors, and it overlaps with the timed outcomes; (6) selecting the fastest of two trials may bias associations; (7) no kinetic variables were measured; and (8) the cross-sectional design precludes causal inference. Future studies should use larger samples analysed by sex, instrumented starting blocks, documented reliability, and training interventions.

5. Conclusion

Among these PJKR FIKK UNM students, reaction time and early split times were strongly associated with 100-m time. The variance explained by the start-technique block (73%) was due almost entirely to reaction time. Push projection angle, initial trunk inclination, and ground contact time showed no significant association, and the results for step length and step frequency were small to moderate and unstable. Reaction time may be a marker of overall sprint ability rather than a trainable cause. These exploratory, correlational findings need confirmation in larger sex-specific samples with kinetic measures and intervention designs.

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