FORCE-VELOCITY PROFILING FOR SHORT ICE HOCKEY SKATING SPRINTS: EFFECT OF EXPONENTIAL FUNCTION

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A high-speed digital video camera can be used to obtain highly reliable short-sprint split times. Split time data can be used to estimate instantaneous position, velocity, and acceleration by fitting an exponential function to the known positional data yielding force-velocity (F-V) profiles that may provide more information than just sprint times alone. The purpose of this study was to evaluate the between-rater reliability of different exponential functions used to estimate instantaneous data. A high-speed digital video camera was used to obtain split times from eleven male high-school ice hockey players performing a 6.10 m sprint and a separate top speed test. Including an optimization parameter and using a player's measured maximal horizontal velocity instead of estimating it tended to produce better between-rater reliability.

KEYWORDS: power, mechanical effectiveness, maximal velocity, digital video camera, acceleration.

INTRODUCTION: Coaches often use short sprints less than 20 m in length to assess an ice hockey player's capabilities (Bond, Bennett, & Noonan, 2018), but sprint times do not provide direct insight into underlying mechanical properties of the sprint, such as power and force. A macroscopic analysis dependent upon inverse dynamics using readily available environmental temperature and pressure, the ice hockey player's height and mass, and sprint split times can be used to generate force-velocity (F-V) profiles (Stenroth, Vartiainen, & Karjalainen, 2020; Perez, Guilhem, & Brocherie, 2019). The resulting F-V profile includes theoretical maximal horizontal force (F_O), maximal horizontal velocity (V_O), and maximal horizontal power (P_{MAX}), amongst others, which can be used to determine the mechanical limits of the ice hockey player and may enhance talent identification, longitudinal monitoring, and program development. Split times, which can be obtained reliably using an inexpensive high-speed digital camera positioned with its optical axis perpendicular to the sprint line, and an exponential function are used to estimate the ice hockey player's instantaneous position, velocity, and acceleration. The function is fit by altering two terms, the maximal horizontal velocity ($\widehat{V_{MAX}}$) and acceleration constant ($\hat{\tau}$), to minimize the sum of squares difference between the known time and position obtained from split times and the estimated time and position. An optional third term ($\hat{C}$) optimizes the first split time and may improve reliability (Stenroth et al., 2020). This is because misidentification of the start of the sprint due to the inability to accurately identify the first instance of horizontal acceleration on digital video erroneously shortens or elongates the first split time and can cause drastic under or overestimation of the F-V profile. To use this method, it is necessary that the ice hockey player reaches V_{MAX} within one of the obtained split times. Of concern is that not all ice hockey players reach V_{MAX} in short sprint distances that can be captured using standard high-speed digital cameras or ice hockey rinks. Therefore, the function may not appropriately estimate the $\widehat{V_{MAX}}$ term, resulting in poor validity and reliability of the F-V profile. A separate top speed test could be conducted to measure the player's V_{MAX} and this fixed value could be used in the function instead, possibly improving F-V profile reliability. The purpose of this study was to assess the between-rater reliability of F-V profiles obtained from split times of a 6.10 m sprint. It was hypothesized that exponential functions estimated using both $\hat{C}$ and a fixed V_{MAX} from a top speed test would yield better F-V profile between-rater reliability than when they were estimated without $\hat{C}$ and with $\widehat{V_{MAX}}$.

METHODS: Eleven male ice hockey players (16.0 ± 1.1 y, 1.82 ± 0.03 m, 77.7 ± 9.9 kg) from an Upper Midwest, USA high school varsity ice hockey team participated in the study. Goaltenders were excluded from the study. The Sanford Health Institutional Review Board approved this study and players were informed about the benefits, risks, and experimental procedures before providing their informed, written, voluntary consent. Assent was obtained from players 17 years of age and younger and consent was obtained from their parent or legal guardian. A sprint line was drawn on the ice 3.05 m away from and parallel to the sideboards. A high-speed digital video camera with a standard lens recording at 120 Hz was placed 15.24 m from the sprint line. Banners were hung from the glass so that a vertical color band was aligned with the start (0 m) and the end of the sprint line (15.24 m (50 ft)) relative to the digital video camera to correct for parallax. To perform the top speed test, players were positioned on the goal line on the opposite side of the rink relative to the sprint line. They were instructed to skate down the length of the ice and around the net in a counterclockwise fashion with their stick. The players then skated as fast as possible along the sprint line. To determine V_{MAX}, a single investigator examined the digital video and selected the frames when each player's sacrum passed by the banners and converted the elapsed number of frames into time in seconds. V_{MAX} was calculated as the mean velocity over 15.24 m. Players then completed an 18.29 m sprint by starting at one end of the sprint line in a stationary, two-point stance with their lead foot positioned behind the start line. When they felt ready, players skated as fast as they could along the length of the sprint line. Two investigators independently examined the digital videos of these sprints and selected the frames when each player's sacrum passed by each split mark, which corresponded with 0, 0.76, 1.52, 2.29, 3.05, 4.57, and 6.10 m along the sprint line. More frequent splits were captured for the first 3.05 m because this represents a critical transition and rapid acceleration period of the sprint. Although they sprinted a longer distance, only data from the first 6.10 m was used for this analysis because a player would not reach V_{MAX} in this short distance and it represents a commonly observed short burst of acceleration required in a game setting. Split time data was then used to estimate terms in four functions using a publicly available generalized reduced gradient nonlinear solver (Morin & Samozino). The functions were:

1) Estimate $\hat{C}$, $\widehat{V_{MAX}}$, and $\hat{\tau}$: $x(t) = \widehat{V_{MAX}} \cdot \left(t + \hat{C} + \hat{\tau} e^{-(t+\hat{C})/\hat{\tau}}\right) - \widehat{V_{MAX}} \cdot \hat{\tau}$

2) Estimate $\hat{C}$ and $\hat{\tau}$, V_{MAX} fixed: $x(t) = V_{MAX} \cdot \left(t + \hat{C} + \hat{\tau} e^{-(t+\hat{C})/\hat{\tau}}\right) - V_{MAX} \cdot \hat{\tau}$

3) Estimate $\widehat{V_{MAX}}$ and $\hat{\tau}$: $x(t) = \widehat{V_{MAX}} \cdot \left(t + \hat{\tau} e^{-t/\hat{\tau}}\right) - \widehat{V_{MAX}} \cdot \hat{\tau}$

4) Estimate $\hat{\tau}$, V_{MAX} fixed: $x(t) = V_{MAX} \cdot \left(t + \hat{\tau} e^{-t/\hat{\tau}}\right) - V_{MAX} \cdot \hat{\tau}$

where t is time, $\hat{C}$ is the estimated optimization parameter, $\widehat{V_{MAX}}$ is the estimated maximal horizontal velocity, V_{MAX} is the measured maximal horizontal velocity during the top speed test, and $\hat{\tau}$ is the estimated acceleration constant. Dependent variables in this study included frame number, split time, estimated position, F_O, V_O, and P_{MAX}. SPSS was used to estimate random factor variance components for ice hockey player (p), rater (r), and ice hockey player by rater compounded with error (p×r, e). Absolute standard error and reliability coefficients were then calculated to assess between-rater reliability. Descriptive statistics and mean differences between-raters were also used to assess between-rater reliability.

RESULTS AND DISCUSSION: Timing short sprints using a high-speed digital video camera is a valid and reliable method, but reliably identifying the first frame where horizontal acceleration begins is challenging. In the present study, there was poor reliability for the first frame selected to start the sprint, but better reliability for all remaining splits (Table 1). This is similar to the findings of other studies (Stenroth et al., 2020) as visually separating initial noise and the true start of horizontal acceleration is challenging. However, in subsequent splits where the athlete already has an appreciable horizontal velocity, reliably identifying the frame when the chosen anatomical landmark passes by a split mark improves. Any time error caused by misidentification of the frame corresponding to start the sprint would not only affect the time to reach the 0.76 m split but would also affect all remaining splits as a constant time error.

Table 1: Absolute standard error (SEM) for frame selection. Data presented in frames.

Split (m)	SEM (frames)
.00	7.45
.76	1.57
1.52	.80
2.29	.57
3.05	.63
4.57	.57
6.10	.60

Table 2: Absolute standard error (SEM) in seconds and reliability coefficient (Φ) for the split times used to estimate the terms in the exponential functions. Data presented in seconds and reliability coefficient.

Split (m)	Function 1		Function 2		Function 3 and 4	
	SEM (s)	Φ	SEM (s)	Φ	SEM (s)	Φ
0.76	.042	.58	.014	.89	.028	.00
1.52	.056	.51	.028	.75	.057	.00
2.29	.070	.53	.042	.72	.057	.00
3.05	.063	.65	.042	.83	.064	.00
4.57	.078	.63	.049	.79	.064	.17
6.10	.078	.69	.057	.82	.071	.41

Table 3: Mean [95% confidence interval] for the estimated position (M) and mean difference [95% confidence interval for the difference] between-raters for the estimated position (MD). Data presented in meters.

Split (m)		Function 1	Function 2	Function 3	Function 4
0.76	M	0.75 [0.74, 0.76]	0.77 [0.74, 0.80]	0.67 [0.60, 0.74]	0.58 [0.49, 0.66]
	MD	-0.01 [-0.03, 0.01]	-0.01 [-0.06, 0.04]	-0.02 [-0.15, 0.12]	0.02 [-0.16, 0.19]
1.52	M	1.53 [1.51, 1.54]	1.52 [1.50, 1.55]	1.50 [1.48, 1.52]	1.33 [1.24, 1.43]
	MD	0.00 [-0.03, 0.04]	0.02 [-0.03, 0.08]	0.00 [-0.04, 0.05]	0.03 [-0.15, 0.21]
2.29	M	2.29 [2.27, 2.31]	2.26 [2.22, 2.30]	2.30 [2.27, 2.33]	2.12 [2.05, 2.19]
	MD	0.01 [-0.03, 0.05]	0.04 [-0.04, 0.13]	0.01 [-0.05, 0.06]	0.04 [-0.10, 0.18]
3.05	M	3.09 [3.06, 3.11]	3.05 [3.01, 3.09]	3.12 [3.09, 3.15]	2.97 [2.91, 3.02]
	MD	0.00 [-0.04, 0.04]	0.05 [-0.04, 0.13]	0.00 [-0.06, 0.05]	0.02 [-0.09, 0.14]
4.57	M	4.52 [4.51, 4.54]	4.49 [4.43, 4.54]	4.55 [4.53, 4.57]	4.53 [4.51, 4.55]
	MD	-0.01 [-0.04, 0.01]	0.04 [-0.06, 0.14]	-0.01 [-0.06, 0.03]	-0.01 [-0.05, 0.02]
6.10	M	6.11 [6.11, 6.12]	6.11 [6.05, 6.16]	6.08 [6.06, 6.10]	6.30 [6.23, 6.37]
	MD	0.00 [0.00, 0.01]	0.04 [-0.06, 0.15]	0.00 [-0.04, 0.05]	-0.04 [-0.17, 0.10]

Table 4: Absolute standard error (SEM) in seconds and reliability coefficient (Φ) for the force-velocity profile characteristics of theoretical maximal horizontal force (F_O), maximal horizontal velocity (V_O), and maximal horizontal power (P_{MAX}). Data presented in N·kg^{-1}, m·s^{-1}, or W·kg^{-1} and reliability coefficient.

	Function 1		Function 2		Function 3		Function 4	
	SEM	Φ	SEM	Φ	SEM	Φ	SEM	Φ
F_O (N·kg^{-1})	1.046	.45	.262	.69	3.125	.00	.912	.23
V_O (m·s^{-1})	1.865	.38	.042	.88	.841	.30	.035	.90
P_{MAX} (W·kg^{-1})	.558	.76	.552	.75	2.800	.00	2.042	.32

Between-rater differences in this frame selection has negative impact on the reliability of the resulting F-V profile. In particular, this is problematic when different raters are used to assess different groups of players and it is desirable to compare the group performances. This time error necessitates the addition of a constant value term in the function to correct the misidentification of the start of the sprint. $\hat{C}$ was introduced for this reason and its addition in the function improved between-rater reliability of the split times (Table 2, Function 1 and 2 vs 3 and 4). When generating F-V profiles, it is most appropriate to complete a sprint of a long enough distance to ensure that a player's V_{MAX} is captured during the sprint. However, when a shorter sprint is completed and a player's V_{MAX} is not obtained, it appears that constraining the $\widehat{V_{MAX}}$ term to equal the V_{MAX} measured during a separate top speed test further improves between-rater reliability (Table 2, Function 1 vs 2). This supports the hypothesis. Split times or optimized split times adjusted using $\hat{C}$ are then used to estimate instantaneous position. The two functions that utilized $\hat{C}$ tended to produce a narrower range between the lower and upper 95% confidence interval bounds for the mean difference between-raters, suggesting that using optimized split times to estimate position results in better agreement of estimated position between-raters (Table 3, Functions 1 and 2 vs 3 and 4). The estimated position for the two functions that utilized $\hat{C}$ also tended to be more similar to the known position, particularly for the 0.76 m split, in comparison to the two functions that did not use $\hat{C}$. Superior reliability in split times used to estimate instantaneous position, agreement between-raters in the estimated instantaneous position, and fit between the estimated instantaneous position and the known position should yield superior reliability for the F-V profile. The two functions that utilized $\hat{C}$ tended to produce better between-rater reliability for F_O, V_O, and P_{MAX} than when $\hat{C}$ was not used (Table 4, Functions 1 and 2 vs 3 and 4). Further, between-rater reliability of the F-V profile was best when $\hat{C}$ and $\hat{\tau}$ are estimated and V_{MAX} is fixed to the value obtained from the top speed test further supporting the hypothesis (Table 4, Function 1 vs 2).

CONCLUSION: Compared to simple sprint times, quantifying an F-V profile provides additional insight into the characteristics underlying performance or the mechanical limits of a player and may enhance player development strategies. Reliable F-V profiles generated from split times captured using a high-speed digital video camera are contingent upon reliable estimates of instantaneous position, velocity, and acceleration. The addition of a time error constant corrective value $\hat{C}$ to the function and constraining the $\widehat{V_{MAX}}$ term to equal the V_{MAX} measured during a separate top speed test improves between-rater reliability for these short sprints. Although between-rater reliability is just one aspect of reliability and the effect of these functions on measures of within-rater, between-player, and within-player reliability and validity should also be assessed, the results of this study provide preliminary support. Doing a separate top speed test is easy, would require less than five extra minutes of ice time for a full ice hockey team, and may provide additional informative data about a player's mechanical limits compared to just a short sprint alone.

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