Relay exchanges in elite short track speed skating

HEXT, Andrew <http://orcid.org/0000-0003-2070-6601>, HELLER, Ben <http://orcid.org/0000-0003-0805-8170>, KELLEY, John <http://orcid.org/0000-0001-5000-1763> and GOODWILL, Simon <http://orcid.org/0000-0003-0638-911X>

Routledge
Taylor & Francis Group

ORIGINAL ARTICLE

Relay exchanges in elite short track speed skating

ANDREW HEXT ⓘ, BEN HELLER ⓘ, JOHN KELLEY ⓘ, & SIMON GOODWILL ⓘ

Centre for Sports Engineering Research, Sheffield Hallam University, Sheffield, UK

Abstract

In short track speed skating, the relay exchange provides an additional strategic component to races by allowing a team to change the skater involved in the pack race. Typically executed every 1½ laps, it is the belief of skaters and coaches that during this period of the race, time can be gained or lost due to the execution of the relay exchange. As such, the aim of this study was to examine the influence of the relay exchange on a team's progression through a 5000 m relay race. Using data collected from three World Cup relay events during the 2012–2013 season, the time taken to complete the straight for the scenarios with and without the relay exchange were compared at different skating speeds for the corner exit prior to the straight. Overall, the influence of the relay exchange was found to be dependent on this corner exit speed. At slower corner exit speeds (12.01–13.5 m/s), relay exchange straight times were significantly faster than the free skating scenario ($P < 0.01$). While at faster corner exit speeds (14.01–15 m/s), straight times were significantly slower ($P < 0.001$). The findings of this study suggest that the current norm of executing relay exchanges every 1½ laps may not be optimal. Instead, varying the frequency of relay exchange execution throughout the race could allow: (1) time to be gained relative to other teams; and (2) facilitate other race strategies by providing an improved opportunity to overtake.

Keywords: *Analysis, tactics, performance*

Introduction

Short track speed skating involves individual and relay events performed counter-clockwise on a 111.12 m oval. In all events, races involve four to eight skaters racing head to head at speeds exceeding 12.5 m/s (Landry, Gagnon, & Laurendeau, 2013). To earn a medal in short track speed skating, a skater or team must advance through several rounds of qualification to reach the medal contest. Advancement through the competition, and medal colour, is dependent on the finishing position in that race only i.e., finishing time, with respect to other races, is irrelevant. As such, strategic aspects such as 'when and where' to overtake and 'how long' to draft for are thought to play an important role for success in short track speed skating (Muehlbauer & Schindler, 2011; Quinney, 1990).

Raced over 3000 m (27 laps) for women and 5000 m (45 laps) for men, the relay event provides an additional strategic component to short track speed skating races: the relay exchange. Excluding the final two laps of the race, the relay exchange allows a team, consisting of four skaters, to change the skater involved in the pack race at any time (International Skating Union, 2014). With change in race responsibility initiated by touch, the relay exchange is typical executed by the skater involved in the pack race (skater 1) pushing the new skater (skater 2) at the start of the straight (Figure 1).

In a typical race, teams will execute the relay exchange every 1½ laps, resulting in 17 exchanges over 3000 m and 29 exchanges over 5000 m. It is the belief of skaters and coaches that during this period of the race, time can be gained or lost relative to other teams depending on how effectively these relay exchanges are executed (Osborough & Henderson, 2009; Riewald, Broker, Smith, & Otter, 1997). For this reason, current investigations on the relay exchange have used simulated race conditions to assess the mechanisms that underlie the execution of the relay exchange (Osborough & Henderson,
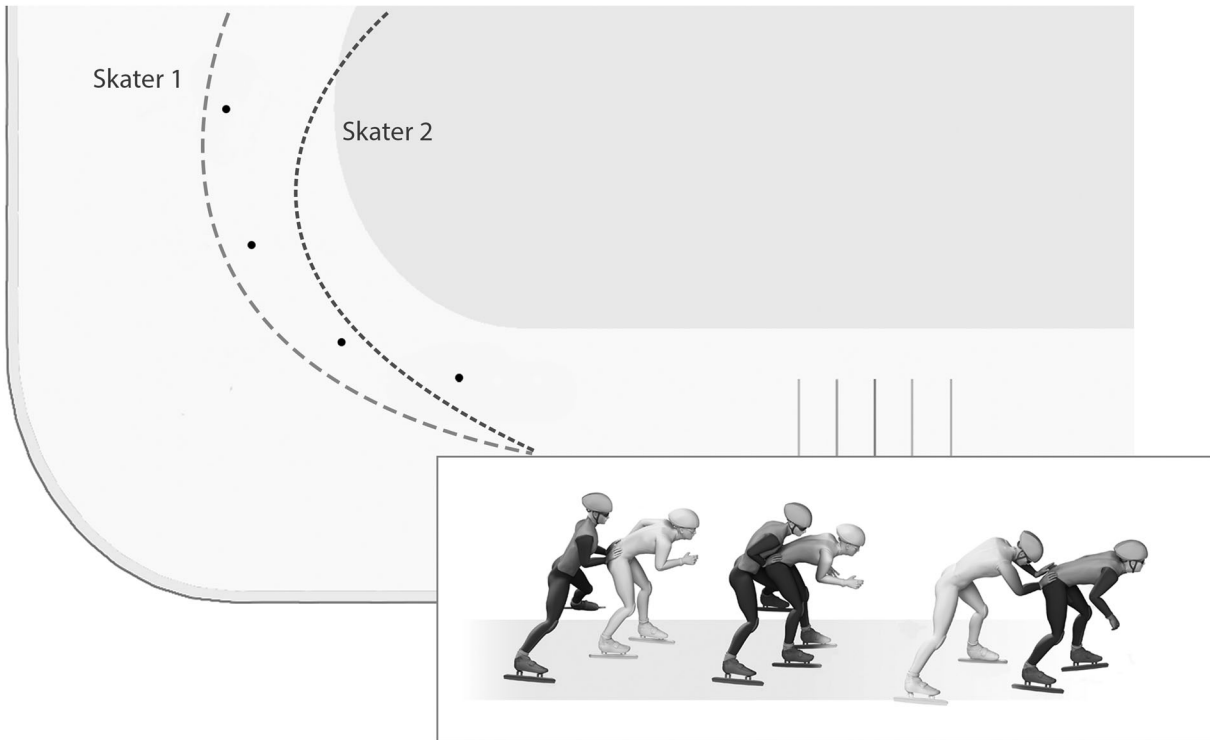

Figure 1. The relay exchange execution. In preparation for the exchange, skater 2 builds up speed on the inside of the track to arrive at the start of the straight with a similar speed to skater 1. Post relay exchange, skater 1 recovers inside of the track for future involvement in the race. Adapted from *Short track speed skating*, by Antoni Gràcia, 2014. Retrieved from https://www.behance.net/gallery/9912955/Short-track-speed-skating. Adapted with permission.

2009; Riewald et al., 1997). While the occurrence of the relay exchange itself, has yet to be investigated during elite short track speed skating relay races.

As such, the aim of this study was to examine the influence of the relay exchange on a team's progression through the 5000 m short track relay. To assess the effect of the relay exchange occurrence, the time taken to complete the straight, termed straight time, was compared for the scenarios with and without the relay exchange. To provide a more detailed insight, straight times were compared at different skating speeds for the corner exit prior to the straight.

Method

Performance data

Data were collected from three International Skating Union Short Track World Cups during the 2012–2013 season. The data set consisted of 20 men's 5000 m relay races: 12 heats, 6 semi-finals and 2 A finals. Each race was captured with a single Sony HDR PJ260VE camcorder operating at 50 Hz (progressive scan). The camera was mounted on a tripod in the spectator gallery opposite to the relay start line and fixed approximately 45° to the rinks longitudinal axis (Figure 2). The cameras field of view was adjusted to capture the full rink surface. All competition footage

was provided by Great Britain Short Track Speed Skating with ethics approval obtained from the Faculty of Health and Wellbeing Ethics Committee, Sheffield Hallam University, UK.

Calibration procedure

For each race, a two-dimensional direct linear transformation (DLT) was used to calibrate the rink surface (Walton, 1981). Using bespoke software, six track marking blocks of known position (Figure 2) were manually digitised to calculate the eight DLT coefficients necessary to reconstruct a 2D position of a point on a plane. A frame approximately two seconds into the captured footage was analysed to ensure: (1) that the camera had settled in its fixed position after record was pressed; and (2) the track marking blocks had not yet been displaced from their correct location. In accordance with Bullock, Martin, and Zhang (2008), six sector lines that split the track into three main sectors, the straight, corner entry and corner exit, were overlaid onto the race footage by extending lines through the digitised track marking blocks (Figure 2). The typical mean reconstruction error of the calibration procedure was found to be 0.05 m (SD = 0.05), on a 60 × 30 m rink surface. For a detailed description of the method
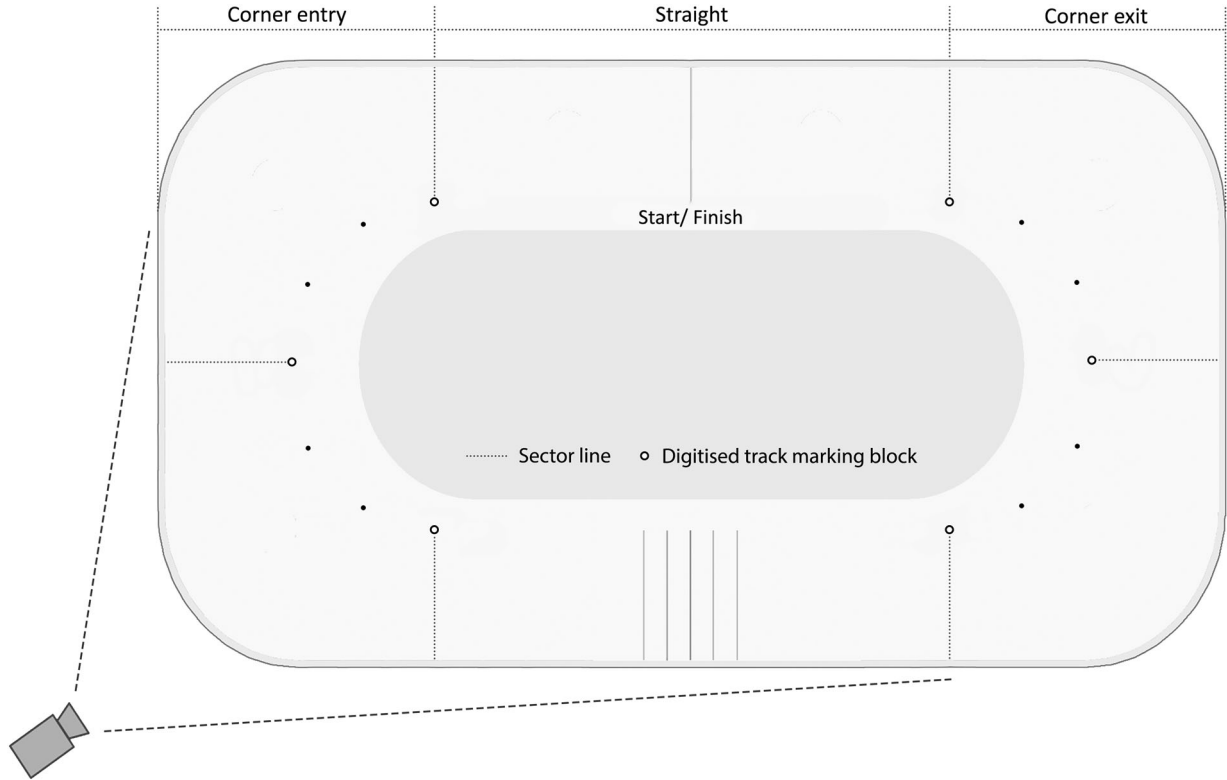
Figure 2. The experimental setup, highlighting: (1) the camera location in relation to the rink; (2) the six digitised track marking blocks used for the planar calibration; and (3) the sector lines that split the track into three main sections.

used to evaluate the planar calibration, see part two of Dunn, Wheat, Miller, Haake, and Goodwill (2012).

Race analysis procedure

For each race, the start was defined by the first frame where the start gun was seen to fire. All subsequent temporal race measurements were calculated from the camera frame rate at a resolution of 0.02 seconds. For the entirety of the race, and for each team, the absolute time and rink position were manually digitised at the point where the lead blade of the racing skater first passed through a sector line (270 unique spatio-temporal events per team). If a skater fell, no further measurements were collected for that team. All manual digitisation was performed by a single operator using bespoke software.

Data analysis

For each instance of a relay exchange i.e., the scenario where a relay exchange was executed during the straight, four metrics were calculated using the absolute time and rink position data (Figure 3(a)): (1) corner exit time: the time taken from the apex sector line to the exit sector line; (2) straight time: the time taken from the exit sector line to the entry

sector line; (3) apex block distance: the distance along the apex sector line from the track marking block to the skater's lead blade; and (4) exit block distance: the distance along the exit sector line from the track marking block to the skater's lead blade. The four metrics were also calculated for the scenario where no relay exchange was executed during the straight, termed free skating.

Corner exit speed was calculated by dividing the distance travelled by the skater during the sector, termed corner exit distance, by the corner exit time (t_1). Similar to Yule and Payton (2000), who modelled skater trajectories as an arc length of a circle, we assumed that during the corner exit skaters turned around a centre of rotation located at the corner centre (Figure 3(b)). This allowed corner exit distance to be calculated by modelling the skater's trajectory as an arc length of an ellipse using the following equation

$$\text{Corner exit distance} \approx 0.25 \left\{ \pi(a+b) \left[1 + \frac{3\left(\frac{a-b}{a+b}\right)^2}{10 + \sqrt{4 - 3\left(\frac{a-b}{a+b}\right)^2}} \right] \right\} \quad (1)$$
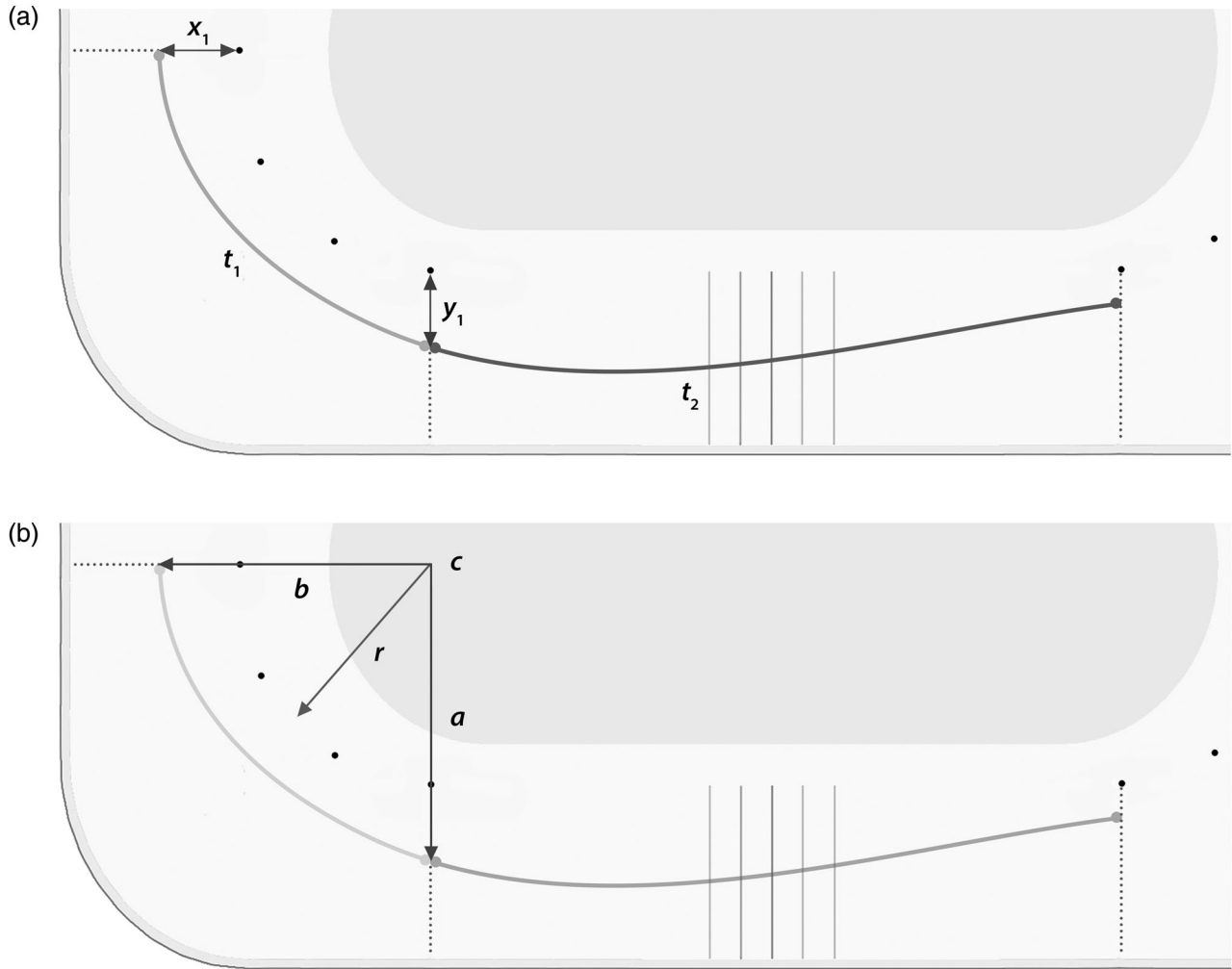
Figure 3. (a) The four metrics calculated for each instance of a relay exchange or free skating scenario: corner exit time (t_1), straight time (t_2), apex block distance (x_1) and exit block distance (y_1). (b) The centre of rotation (c), corner radius (r) and two metrics used to calculate corner exit distance: the minor (b) and major (a) radii.

where a is the ellipse major radii, the sum of the exit block distance (y_1) and corner radius (r); and b is the ellipse minor radii, the sum of the apex block distance (x_1) and corner radius (r) (Figure 3(b)).

Reliability and validity

The level of human error in the race analysis procedure was assessed using a randomly selected relay race. All 270 spatio-temporal metrics were digitised for a single team on two occasions, separated by a day. The root mean square error (RMSE) for both spatial and temporal metrics was 0.02–0.03 m and 0.002–0.003 seconds, respectively. As described by Hext, Heller, Kelley, and Goodwill (2016) for straight time, the validity of both temporal metrics was assessed during a simulated relay race at the National Performance Centre for Short Track Speed Skating, Nottingham, UK. Sector times,

measured as per the race analysis procedure, were compared to synchronised cameras located perpendicular to the sector lines. An RMSE of 0.011 seconds was found. Collectively, the reliability and validity for both spatial and temporal metrics were within the mean 0.05 m reconstruction error and the 0.02 second camera resolution.

Statistical analysis

All data were entered into the SPSS statistical software package for analysis (IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp). The data were discretised into 0.5 m/s groups based on the calculated corner exit speeds; with a minimum of 10 instances of both relay exchange and free skating scenarios required for further analysis. For each group, differences in straight time between the relay exchange and free skating scenarios

were compared using an independent *t*-test (if data were normally distributed) or Mann–Whitney *U*-test (if data were not normally distributed). To test for normality, Shapiro–Wilk and Levene tests were performed with the significance level set at $P < 0.05$ for all statistical tests. Effect sizes were also calculated using Pearson's correlation coefficient, as described by Field (2009). The magnitudes of the correlations were interpreted using Cohen's thresholds where: < 0.1, is trivial; 0.1–0.3, small; 0.3–0.5, moderate; and >0.5, large (Cohen, 1988).

Results

Of the 1968 relay exchanges and 1971 free skating instances analysed, 97.8% of the data were discretised into seven 0.5 m/s groups ranging from 11.51 to 15 m/s. The distribution of relay exchange and free skating instances for the seven groups are reported in Table I. Note the shift towards slower corner exit speeds for the relay exchange scenario compared to the free skating scenario. All groups greater than 12.5 m/s violated the assumptions of normality and thus were analysed using a Mann–Whitney *U*-test instead of an independent *t*-test.

The descriptive statistics, significance test results and effect sizes for each corner exit speed are presented in Table I. At corner exit speeds lower than 13.5 m/s, straight times were significantly faster during the relay exchange scenario ($P < 0.01$). The exception being the 11.51–12 m/s group, where no significant difference was observed ($P = 0.056$). This group, however, did exhibit the largest effect size ($r = 0.32$); the magnitude of the effect decreasing from moderate to small, as corner exit speed increased.

For corner exit speeds of 13.51–14 m/s, no significant difference was found between relay exchange and free skating scenarios ($P = 0.093$), with the magnitude of the effect trivial ($r = -0.05$).

At corner exit speeds greater than 14 m/s, straight times were significantly slower during the relay

exchange scenario ($P < 0.001$). Here, the magnitude of the effect increasing negatively, from small to moderate, as the corner exit speed increased.

Discussion

The aim of this study was to examine the influence of the relay exchange on a team's progression through the 5000 m short track relay. To provide a more comprehensive insight, straight times for relay exchange and free skating scenarios were compared at different skating speeds for the corner exit prior to the straight. Overall, the influence of the relay exchange was found to be dependent on these corner exit speeds; having a positive effect at slower speeds and a negative effect at faster speeds.

At slower corner exit speeds, the positive effect of the relay exchange, that is, faster straight times for the relay exchange scenario were consistent with other elite sports relays. In swimming, the occurrence of the relay exchange accounted for significantly faster mean individual split times when compared to individual events (Skorski, Etxebarria, & Thompson, 2016). While in athletics, the relay exchange had a significant positive effect on progression through the 4×100 m relay, due to the baton being passed forward by up to 2 m for no loss in time (Ward-Smith & Radford, 2002). This is analogous to the short track relay exchange where instead of the baton, the skater active in the race moves forward a body length for no loss in time. Despite this, however, as corner exit speed increased the positive influence of the relay exchange transitioned to having no, and then to a negative effect, highlighted by the Pearson correlation coefficient values. This suggests that other factors caused the influence of the relay exchange to change as the corner exit speed increased; three of which are described below.

One explanation for this could be that prior to the relay exchange, the incoming skater (skater 2) has to build up speed similar to that of the outgoing skater

Table I. Descriptive statistics (mean ± standard deviation), significance test results and effect sizes of relay exchange and free skating straight times (s) at different corner exit speeds (m/s).

Corner exit speed	n	Relay exchange	Free skating	Test statistic	P	Effect size
11.51–12	36 (25 RE, 11 FS)	2.55 ± 0.11	2.62 ± 0.12	−1.982[a]	0.056	0.32
12.01–12.5	135 (91 RE, 44 FS)	2.48 ± 0.07	2.52 ± 0.08	−3.24[a]	0.002	0.27
12.51–13	449 (307 RE, 142 FS)	2.40 ± 0.07	2.44 ± 0.07	15045[b]	0.000	0.24
13.01–13.5	960 (616 RE, 344 FS)	2.34 ± 0.07	2.35 ± 0.07	88043[b]	0.000	0.14
13.51–14	1158 (600 RE, 558 FS)	2.28 ± 0.07	2.27 ± 0.07	157899[b]	0.093	−0.05
14.01–14.5	839 (272 RE, 567 FS)	2.23 ± 0.06	2.20 ± 0.06	54366.5[b]	0.000	−0.24
14.51–15	277 (42 RE, 235 FS)	2.19 ± 0.05	2.15 ± 0.05	2452.5[b]	0.000	−0.31

Notes: RE = relay exchange, FS = free skating. Statistical test performed: [a]Independent *t*-test; [b]Mann–Whitney *U*-test. Magnitude of effect measured using Pearson's correlation coefficient.

active in the pack race (skater 1), on the inside of the track. As such, the speed is generated over a tighter corner radius, requiring more energy expenditure to overcome the higher cornering forces (Rundell, 1996). Therefore, at faster corner exit speeds, matching the speed of the active skater may be more difficult for the incoming skater. The consequence of which can be explored by modelling the relay exchange as a one-dimensional collision, using the coefficient of restitution to represent the efficiency of energy exchange during skater contact reported by Riewald et al. (1997). By keeping all variables constant, except the speed of the incoming skater, as the difference in skating speed prior to the relay exchange increases, the speed of the incoming skater after the relay exchange decreases (relative to the speed of the outgoing skater prior to the relay exchange).

Another explanation could be that when the outgoing skater pushes the incoming skater at the start of the straight, the outgoing skater applies a force over the duration of contact – an impulse. Based on the impulse-momentum theorem, this impulse causes the incoming skaters momentum and thus velocity to change (as the mass of the skater remains constant). If we assume that, independent of skating speed, the impulse imparted by the outgoing skater during the push remains constant for all relay exchanges (both the force applied and push duration); as corned exit speed increases: (1) the relative contribution of the impulse would decrease, due to the incoming skater having a larger momentum prior to contact; and (2) the incoming skater would have less distance to accelerate after the relay exchange due to being further down the straight. Potentially explaining why Osborough and Henderson (2009) found relay exchanges initiated greater than 4.5 m from the start of the straight had slower mean straight skating speeds compared to relay exchanges initiated from 4 to 4.5 m.

An additional finding from this study was the observed difference in distributions for relay exchange and free skating instances over the seven corner exit speed groups. Specifically, the greater number of relay exchange instances that occurred at slower corner exit speeds compared to the greater number of free skating instances that occurred at faster corner exit speeds. While the difference in distributions does not affect the comparison of relay exchange and free skating straight times, due to both statistical tests being robust to unequal sample sizes, the difference in distributions does suggest that either: (1) the additional constraints of the relay exchange scenario, such as the outgoing skater ensuring that they are well positioned to push the incoming skater, results in a lower upper limit of corner exit speed; or (2) that the outgoing skater is slower during the relay exchange corner exit due to fatigue; the corner exit representing the final period of the skaters current involvement in the pack race. This is in agreement with Riewald et al. (1997), who reported losses in speed for the outgoing skater prior to relay exchange contact.

It is clear that further work is needed to understand the observed difference in distributions for relay exchange and free skating instances in addition to why the influence of the relay exchange is dependent on the speed of the race. We suggest that future studies should start by validating the mechanisms proposed in this study. Importantly, these studies necessitate the accurate measurement of instantaneous skater speed during the corner exit and prior to/ post the relay exchange.

When considering the relay exchange as a strategic component of the 5000 m relay, it is important to note that a negative pacing strategy is typically skated, that is, the race starts slow and finishes fast. Therefore, the findings of this study suggest that varying the frequency of when a team executes relay exchanges could improve performance compared to the current norm of executing relay exchanges every 1½ laps (note, in this study, 96% of the relay exchanges analysed were executed every 1½ laps). For example, at slower speeds increasing relay exchange frequency such that relay exchanges are additionally executed while other teams are free skating could allow time to be gained relative to these teams. While during faster race speeds, typical of the race end, decreasing the frequency of relay exchanges could likewise allow time to be gained relative to other teams in the race. This ability to gain time could also facilitate other race strategies. For example, drafting i.e., one skater, skating closely behind another, has been shown to reduce both heart rate and blood lactate in short track speed skating (Hoshikawa et al., 2005; Rundell, 1996). Thus allowing a skater or team to conserve energy for the later stages of the race, where improved performance has been shown to result in better final race position (Konings, Noorbergen, Parry, & Hettinga, 2016). The difficulty in overtaking, however, has been cited as a reason why skaters and coaches are reluctant to utilise drafting as a race strategy (Hoffman, Listemann, McManaman, & Rundell, 1998). Increasing or decreasing the frequency of relay exchanges executed, depending on the speed of the race, could alleviate these difficulties by providing an improved opportunity to overtake. The team performing the fastest straight time scenario for that moment in the race; equating to differences of up to 0.84 m by the end of the straight. These strategies do, however, assume that varying the frequency of relay exchange execution would not increase a

team's net fatigue. It is imperative to minimise the onset of fatigue in speed skating, as Stoter et al. (2016) reported that the associated postural changes have a negative effect on both aerodynamics and skating technique. It is also likely that fatigue would affect the execution of the relay exchange; however, this has not been investigated.

Finally, while these findings could be used by skaters and coaches to improve the strategic utilisation of the relay exchange, the observations are only applicable for the men's 5000 m short track relay. Although other strategic aspects of short track speed skating races, such as the relationship between start and finishing position (Maw, Proctor, Vredenburg, & Ehlers, 2006; Muehlbauer & Schindler, 2011), have shown to exhibit similar relationships when comparing sex, these analyses compared events with the same race distances, unlike the relay events. Subsequently, an equivalent study is needed to understand the influence of the relay exchange on a team's progression during the women's 3000 m short track relay.

Conclusion

The influence of the relay exchange on a team's progression through the 5000 m short track relay was found to be dependent on the corner exit speed, having a positive effect at slower speeds and a negative effect at faster speeds. As such, the current norm of executing relay exchanges every 1½ laps may not be optimal. Instead, varying the frequency of relay exchange execution throughout the race could allow: (1) time to be gained relative to other teams; and (2) facilitate other race strategies by providing an improved opportunity to overtake.

Acknowledgments

Disclosure statement

Funding

Data availability

ORCID

Andrew Hext http://orcid.org/0000-0003-2070-6601
Ben Heller http://orcid.org/0000-0003-0805-8170
John Kelley http://orcid.org/0000-0001-5000-1763
Simon Goodwill http://orcid.org/0000-0003-0638-911X

References

Bullock, N., Martin, D. T., & Zhang, A. (2008). Performance analysis of world class short track speed skating: What does it take to win? *Journal of Performance Analysis in Sport*, *8*(1), 9–18. Retrieved from http://www.ingentaconnect.com/content/uwic/ujpa/2008/00000008/00000001/art00003

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Dunn, M., Wheat, J., Miller, S., Haake, S., & Goodwill, S. (2012, July). *Reconstructing 2D planar coordinates using linear and nonlinear techniques*. Paper presented at the 30th International Conference on Biomechanics in Sports, Melbourne, Australia.

Field, A. (2009). *Discovering statistics using SPSS*. London: SAGE.

Hext, A., Heller, B., Kelley, J., & Goodwill, S. (2016, July). *Measuring straight time in elite short track speed skating relays*. Paper presented at the 11th Conference of the International Sports Engineering Association. doi:10.1016/j.proeng.2016.06.258

Hoffman, E., Listemann, E., McManaman, C., & Rundell, K. W. (1998). Short track speed skating: Analysis of drafting during world championship competition. *Medicine & Science in Sports & Exercise*, *30*(Suppl. 5), 310. doi:10.1097/00005768-199805001-01765

Hoshikawa, H., Yoshino, T., Tamaki, K., Tomita, H., Kato, K., Ishihara, K., … Kawakami, T. (2005). The effects of drafting on blood lactate accumulation during short-track speed skating. *Canadian Journal of Applied Physiology*, *30*(Suppl. 1), S38. doi:10.1139/h2005-156

International Skating Union. (2014). *Special regulations & technical rules: Speed skating and short track speed skating* (as accepted by the 55th Ordinary Congress). Retrieved from http://static.isu.org/media/177903/2014-special-regulations-and-technical-rules-speed-skating-and-short-track-speed-skating-final-version.pdf

Konings, M. J., Noorbergen, O. S., Parry, D., & Hettinga, F. J. (2016). Pacing behaviour and tactical positioning in 1500 m short-track speed skating. *International Journal of Sports Physiology and Performance*, *11*(1), 122–129. doi:10.1123/ijspp.2015-0137

Landry, T., Gagnon, L., & Laurendeau, D. (2013, May). *A GIS-Centric optical tracking system and lap simulator for short track speed skating*. Paper presented at the 10th International Conference on Computer and Robot Vision, Regina, Canada.

Maw, S., Proctor, L., Vredenburg, J., & Ehlers, P. (2006). Influence of starting position on finishing position in World Cup 500 m short track speed skating. *Journal of Sport Science, 24*(12), 1239–1246. doi:10.1080/02640410500497733

Muehlbauer, T., & Schindler, C. (2011). Relationship between starting and finishing position in short track speed skating races. *European Journal of Sport Science, 11*(4), 225–230. doi:10.1080/17461391.2010.499968

Osborough, C., & Henderson, S. (2009, August). *Effect of relay changeover position on skating speed for elite short track speed skaters*. Paper presented at the 27th International Conference on Biomechanics in Sports, Limerick, Ireland.

Quinney, H. (1990). Sport on ice. In T. Reilly, N. Secher, P. Snell, & C. Williams (Eds.), *Physiology of sports* (pp. 275–298). London: E and FN Spon.

Riewald, S. A., Broker, J. P., Smith, S. L., & Otter, J. (1997). Energetics and timing of relay exchanges in short track speed skating. *Medicine & Science in Sports & Exercise, 29*(Suppl. 5), 8. doi:10.1097/00005768-199705001-00045

Rundell, K. W. (1996). Effects of drafting during short-track speed skating. *Medicine & Science in Sports & Exercise, 28,* 765–771. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8784765

Skorski, S., Etxebarria, N., & Thompson, K. G. (2016). Breaking the myth that relay swimming is faster than individual swimming. *International Journal of Sports Physiology and Performance, 11*(3), 410–413. doi:10.1123/ijspp.2014-0577

Stoter, I. K., MacIntosh, B. R., Fletcher, J. R., Pootz, S., Zijdewind, I., & Hettinga, F. J. (2016). Pacing strategy, muscle fatigue and technique in 1500 m speed skating and cycling time trials. *International Journal of Sports Physiology and Performance, 11*(3), 337–343. doi:10.1123/ijspp.2014-0603

Walton, J. S. (1981). *Close-range cine-photogrammetry: A generalized technique for quantifying gross human motion* (Unpublished doctoral dissertation). Pennsylvania State University, Pennsylvania, USA.

Ward-Smith, A. J., & Radford, P. F. (2002). A mathematical analysis of the 4 × 100 m relay. *Journal of Sports Sciences, 20,* 369–381. doi:10.1080/026404102317366627

Yule, T., & Payton, C. (2000). Angle of body lean and speed around the curve in short track speed skating. *Journal of Sports Sciences, 18*(1), 11–12.