ORAL PAPER

Gaze of Olympic speedskaters skating at full speed on a regulation oval: perception-action coupling in a dynamic performance environment

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Abstract Speedskating is the fastest sport performed by humans without the aid of a machine or banking of the surface upon which the action occurs. Champion speedskaters reach speeds in excess of 49 kph on a flat oval of ice where centrifugal forces continually work to throw the skater off the track. The gaze of elite speedskaters was recorded using a mobile eye tracker while skating at full speed on an Olympic Oval. The skating strides were recorded concurrently and the data analyzed in real space and time. The results show that specific gaze behaviors define faster skating speeds. These gaze are unique and show that both the location of the gaze on the ice surface and the afferent information being acquired help the skater maintain perceptual control over the dynamics of the action.

Keywords Eye movements · Perception-action · Motor control · Expertise

Introduction

Elite sport provides an ideal environment to study how the control of gaze and attention contributes to, or detracts from, a high level of performance. Elite performers consistently exhibit perceptual and cognitive advantages over lesser skilled participants, but it is still not known how this occurs in the real world. With the advent of mobile eye trackers it is now possible to determine how speedskaters perceive the oval of ice upon which they skate and how this affects their performance. The gaze of five elite speedskaters was recorded just prior to the 2006 Turin Olympics. Three of the five went on to win medals.

An influential theory that may explain how they control their gaze at speed is the attentional narrowing phenomenon, as reported by Easterbrook (1959). As performance conditions become more complex and more challenging as occurs at high speeds, performance typically deteriorates unless the most optimal cues are fixated at the appropriate times. Skaters must optimize the position over their skates such that in a 3,000 m event, for example, the process of entering the corner, building through the apex and exiting at full speed is repeated more than 14 times, therefore focus and concentration over an extended period of time is required in order to link the required movements at full speed.

Many of the conditions encountered by speed-skaters are also found in auto driving, if one forgets for a moment the differing physiological requirements of the two events. The inherent demands of auto racing have made it an ideal task for investigation of attentional mechanisms, and the eye-movement parameters that underlie those mechanisms. Janelle et al. (1999) assessed the effect on driving performance of a central driving task and a peripheral light detection task over three driving sessions. Driving performance decreased when distracting peripheral lights were present. Distracters in the periphery tend to reduce performance quality due to a reduction in attentional resources. Reaction time to peripheral stimuli increases as the pressure of racing builds and situational demands increase. An Olympic oval is very large space, where teammates, rivals, coaches, and members of the public are in close proximity and where coaches, in particular, often call out or show race times and provide feedback. Even in the midst of all these distractions it is critical that the gaze be oriented in the most optimal way.

Parallels may also be drawn between the gaze control and visual attention requirements found in car driving and that in speedskating in terms of navigating turns.

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Fig. 1 A frame of vision-inaction data as collected in speedskating

Riemersa (1981) found that car drivers depend on edge line motion to maintain the alignment of the car on the road, with the greatest impact during night driving. Land and Lee (1995) and Mestre and Durand (2001) showed that in negotiating curves, a critical cue fixated at high speed is the tangent or reversal point, which is a singular point midway where the inside of the curve changes direction. In speedskating this is often called the apex of the turn and is recognized by coaches and athletes alike to be the location where the body must be positioned over the skates such that the exit from the turn can be made under control. Otherwise at high speeds the athlete cannot prevent skating into the far lane which causes valuable time to be lost. Mestre et al. (2003) stated that the tangent point to the inside of a curve "attracts" gaze and is therefore critical information. It was therefore hypothesized that elite speedskaters should use the tangent point in skating; furthermore faster speeds should be found when the tangent point is used for longer durations.

Methods

Participants

Five elite speedskaters (three males and two females) volunteered for the study. All were members of Canada's Elite Junior or Senior Olympic team of 2006.

Olympic oval

All data was collected at the Olympic oval at the University of Calgary. A lap of track was 400 m with the curves having a radius of 25–26 m in the inner lane. Three lanes each were 4–5 m wide, the inner lane being the practice lane, and the two outside being used for competition. For safety reasons the track was surrounded by large bumper pads.

Equipment

The vision-in-action (VIA) system (Vickers 1996) was used to collect the coupled gaze and skating behaviors of the speedskaters. This system integrated input from a mobile eye tracking system (Mobile Eye) with an external video of the participants' skating. The Mobile Eye is a head-mounted, monocular eye-tracking system that uses corneal reflection to measure eye-line-of-gaze with respect to the field of view. A frame of VIA data is shown in Fig. 1. The gaze image (right), which was recorded by the scene camera on the glasses worn by the skater and shows the scene in front. Superimposed on this image is a gaze circle, which indicated the skater's point of gaze with an accuracy of 1° of visual angle (the diameter of the circle equaled 3°). The motor image (left) was recorded by two external video cameras (one at each end of the oval) that recorded the skating of the participants on the ice. Lap speeds were recorded using timers integral to the Mobile Eye, as well as externally using two cameras that recorded the skating action. Synchronization of the two images was carried out using a commercial editing package, Final Cut Pro (Apple Corp). The images were collected a rate of 30 Hz (or 33.3 ms per frame).

Task

After being calibrated and two laps completed for a warm-up, the skaters skated laps at a rapid training pace.

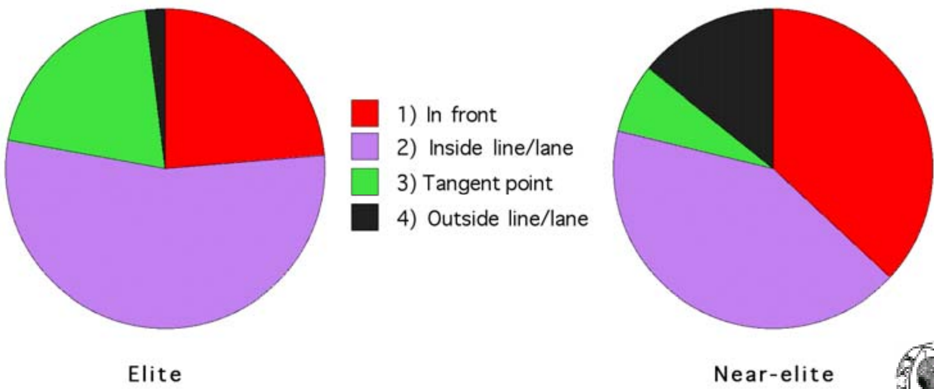


Fig. 2 Percent of gaze directed to four gaze orientations on the ice

Total testing time was approximately 40 min per athlete.

Spatial-temporal coding

The gaze data, as shown in Fig. 1 was coded frame by frame using definitions from previous studies (Patla and Vickers 1997, 2003). Travel fixations were carried along by the skating strides and were held relatively stable on one of four lines on the track (inside practice lane, inside lane 1, inside lane 2, outside lane 2, the tangent on the turn), or frontal in the track path being skated for a minimum of 100 ms. Object fixations were directed to people, cones, the bumper pads or other objects in the field of view for a similar minimum duration. Saccades were rapid shifts of the gaze from one location to another in 66.66 ms or more. Descriptive statistics were used to determine differences due to performance (fast lap times, slow lap times) x gaze orientation (tangent, inside lane, in front, outside lane). Bivariate regression plots were created for lap speeds by gaze orientation. Percent of variance (R^2) was determined in lap speed due to gaze orientation.

Results and discussion

Gaze orientation

The athletes oriented their gaze in front to: the lane in which they were skating (29%); the inside lines or lanes to the left of the direction of travel (49%): the outside lines or lanes to the right of the direction of travel (7%); and to the tangent point (15%). Some interesting differences between the elite and near-elite skaters are shown in Fig. 2. The elite skaters directed more of their gaze to the inside line/lane and tangent point (86%) than the near-elites (60%). The also directed their gaze straight ahead less (24 vs. 37%) or to the right lines or lanes (2 vs. 14%).

Did the orientation of the gaze affect skating speed?

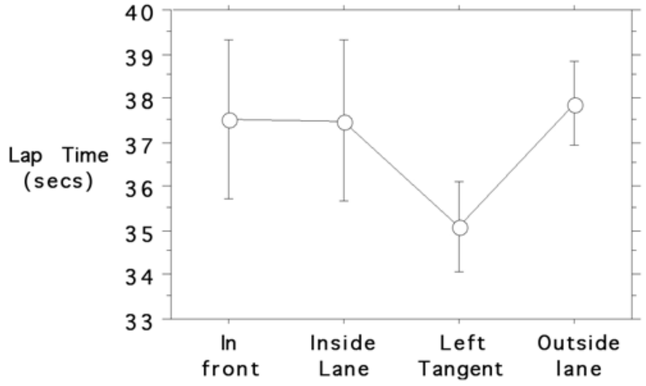


Fig. 3 Mean lap times (seconds) and orientation of the gaze (held stable in front, toward the inside line/lane, toward the tangent point, toward the outside lane/lines)

Figure 3 shows that lap speeds were faster when the gaze was orientated to the inside tangent point. Since speedskaters try to build speed in the turns, this finding is consistent with what is technically desired in the sport.

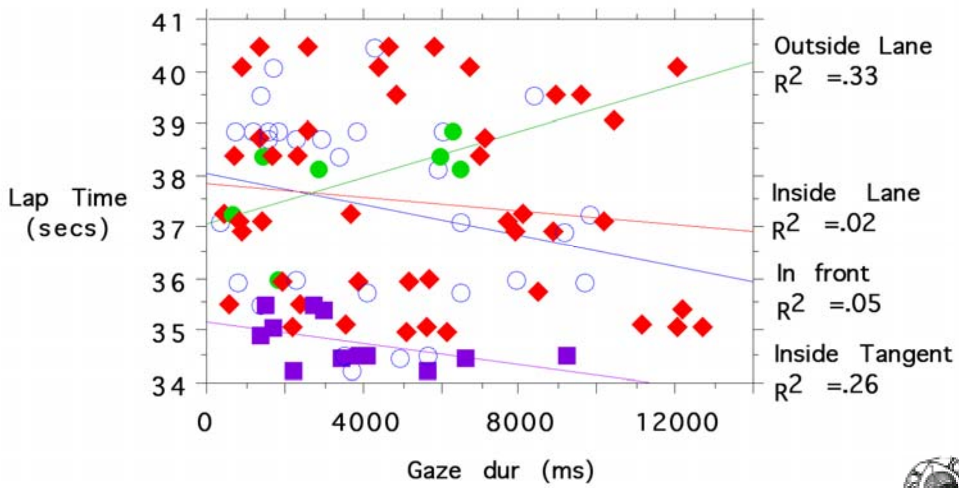
Relationship of lap time (second) and duration (ms) of gaze orientation

The bivariate regression plot for lap time (y-axis) and gaze duration (x-axis) is shown in Fig. 4. Shown is the percent of lap time speed R2 variance accounted for as a function of lap speed. Orienting the gaze to the outside lines or lanes decreased speed, while increasing the duration of the gaze to the lane in front or to the inside line/lane increased speed. The greatest aid to speed was an orientation of the gaze to the tangent point. The longer the athletes maintained their gaze at this location the better able to maintain or increase their speed.

Conclusion

Speedskaters direct their gaze to the lines, spaces and objects on or around the track with faster speeds and more elite performance being defined by an inward rather than outward orientation of the gaze. Analysis of

Fig. 4 Bivariate regression plot showing lap times on the y-axis and gaze duration on the x-axis



the gaze orientation of Olympic speedskaters indicated that faster speeds were achieved when the gaze was oriented to the tangent point of the apex of the turn. Unexpected was the degree of the dissociation between the orientation of the gaze to the tangent point and the direction of skating. Visual inspection of the skater's head often hides the extent to which they orient their gaze inward to the tangent point on the turns. This type of dissociation has been found in driving by Readinger et al. (2001), who measured drivers' steering performance on a straight road when the gaze was directed away from the direction of travel. At eccentricities from 15 to 45° away from the heading direction, subjects' lateral position on the road tended significantly towards their direction of gaze. Elite speedskaters appear to use this gaze to counter the forces of gravity that are acting to pull them off the track. It is also important to note that some of the athletes established their gaze on the tangent point earlier than others. A finer analysis of the gaze at the tangent point will be needed to determine how this affects the athlete's speed.

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