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SPECIAL ISSUE

Biofeedback Reaction-Time Training: Toward Olympic Gold

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As part of a larger training program, applying a new biofeedback protocol for improving reaction time (RT) performance among elite speed skaters at the Canadian Speedskating National Training Center in Montreal, Canada, provided an advantage at the Vancouver 2010 Olympic Games, allowing athletes to assert themselves and claim the best starting position during the event. Each athlete participated in a twice-weekly biofeedback RT training for 5 weeks, for a total of 600 RT practice trials, simulating speed-skating activities such as reacting to commands of ''go to the start,'' ''ready,'' and the sound of a signal from a gun to start. There was an overall improvement in RT performance from the beginning to the end of the 5-week period, with the largest improvement occurring between Weeks 4 and 5 of the training, $F(1, 9) = 679.2$, $p = .001$. *The results suggest that biofeedback protocols will become an essential part of a winning strategy for future interventions in speed skater training.*

Introduction

Reaction time (RT) training is used in a variety of sports. For example, track and field coaches today use RT training with starting blocks to measure RT of sprinters' foot pressure leaving the blocks. Thus, RT is measured in every sanctioned track and field event. As a point of reference, Usain Bolt's RT in Beijing 2008 Olympic Games was .165 seconds in the 100-meter event. Biofeedback techniques have been proven effective for improving performance among recreational, collegiate, and professional athletes in a variety of sports (Crews, Lochbaum, & Karoly, 2000; Zaichowsky & Fuchs, 1988, 1989). However, in short-track speed skating, having the quickest RT combined with a good start allows you the significant advantage to claim the inside position on the first turn, thus forcing your competitors to skate wide or follow you around the 500-meter oval track. Therefore, biofeedback RT training, prestart routine, start technique, start power and acceleration, and finally start confidence, in combination, all play an important role in improving speed-skating sprint success.

Several factors influence speed-skating performance, such as (a) RT and speed during sprinting, (b) muscular strength and endurance during long-distance skating, (c) skating style (e.g., stroke and glide time; push-off velocity and direction) during specific events (e.g., short or long track skating events compared with hockey skating events), and (d) mental focus for sustained attention during a competition (Allinger & van den Bogert, 1997). The four broad categories listed above (a–d) typically interact with each other. For example, factors relating to RT and speed combine with muscular strength to become an index of plyometric power (Behm, Wahl, Button, Power, & Anderson, 2005). Similarly, factors relating to time, such as stroke time and glide time, combine with factors relating to push-off velocity and direction to become an index of technique (de Koning, Foster, Lampen, Hettinga, & Bobbert, 2005). External factors that are not in the control of the skater also influence skating performance on the ice such as the presence of indoor synthetic-polymer ice or the quality of equipment such as aerodynamic suits and clapskates or slapskates, each of which have enhanced the achievements of competitive speed skaters (May, 2000; Sanderson, 2002; Stidwill, Pearsall, & Turcotte, 2010). This article focuses mainly on factors in the control of the skater such as using a new biofeedback method for improving RT performance.

Speed, Safety, and RT

All other things being nearly equal (e.g., very similar speed, strength, technique, ice conditions, equipment), elite speed skaters' performance may vary in very small ways, whereby milliseconds of difference may distinguish a gold and silver medalist. Skills demonstrated at the start of a race, particularly as a skater first pushes off, may depend on individual abilities such as RT (Boer et al., 1987; Lafontaine, 2007). For example, Kuper and Sterken (2002, p. 296) describe factors affecting speed-skating performance such as speed, endurance, and technique and comment about the importance of ''reaction time at the start.'' Whereas RT and speed at the start of a race are important, RT and speed during the race are equally important for affecting safety on the ice. For example, Vickers (2006, p. S102) notes that ''reaction time to peripheral stimuli increases as the pressure of racing builds and situational demands increase,'' affecting safety on the ice even in the midst of constantly changing conditions on the ice as well as distractions such as visually tracking fellow skaters during drafting or attending to a coach's signaling from the sidelines. Safety is also influenced when ''body contact within the rules of the sport occurs that may force the athlete to have an unanticipated reaction, loss of control and probably higher-risk situations'' (Engebretsen et al., 2010, p. 777).

Terms related to the concept of RT have been identified by Nederhof (2007). For example, Nederhof (2007) suggests many terms that are functionally equivalent to *reaction time* such as *reaction speed*, *response time*, *response speed*, *processing time*, *processing speed*, *psychomotor time*, *psychomotor speed*, and other similar terms with precise modifications or variations such as *choice reaction time* or *inhibition reaction time*. Regardless of the specific ways in which we think about the concept of RT, the ability to react to relevant stimuli is an important skill that affects both speed and safety.

Physiological Processes Related to Improving RT Skills

Quinn, Lun, McCall, and Overend (2003) suggest that enhancing RT abilities among athletes will improve both speed and safety during a race. RT processes are affected by both brain and spinal column (central) communication as well as musculoskeletal (peripheral) communication. For example, over the past decade, brain imaging technology has made it possible to implicate some central mechanisms in RT learning. For instance, Nakataa, Yoshiea, Miuraa, and Kudoa, (2010, p. 197) showed brain changes occurring during athlete training that were ''induced by the acquisition and execution of compound motor skills during extensive daily physical training that requires quick stimulus discrimination, decision making, and specific attention.'' Similarly, Rossi and Zani (1991) studied brain-evoked potentials among competitive clay-pigeon shooters and showed that feedback improved RT performance. Similarly, McCarthy and Donchin (1981) suggested that event-related potentials moving in the positive direction at 300 milliseconds (P300) were an index of RT processes that could be used during training of RT skills. In a step toward understanding the communication between the central and peripheral motor systems, some researchers have focused on understanding the somatosensory and cortiospinal communication systems. For example, Kida, Nishihira, Wasaka, Sakajiri, and Tazoe (2004) and Leocani, Cohen, Wassermann, Ikoma, and Hallett (2000) detailed how the somatosensory cortex and its effects on corticospinal communication are directly involved in processes related to RT training.

Peripheral biofeedback techniques, particularly muscle biofeedback techniques for improving RT performance, have been demonstrated several times. For example, Sabourin and Rioux (1979) showed that RT training improved motor and cognitive skills among experimental compared with control subjects, and Schutz, Etnyre, McArthur, and Brelsford (1987) showed that electromyography (EMG) feedback from the triceps brachii contributed to ''improvements in reaction and movement time'' in experimental subjects compared with controls. Specific techniques for feedback sometimes include schedules of reinforcement during training. When schedules of reinforcement are used, Cohen, Richardson, Klebez, Febbo, and Tucker (2001) suggest using a continuous schedule of reinforcement to achieve the greatest improvement in RT abilities. Although there have been several studies examining the use of biofeedback for improving performance among athletes, including RT performance, there have been no reports about the biofeedback training components for improving RT training among elite speed skaters. In addition to biofeedback techniques, other types of physical and mental training techniques may influence improvements in RT processes.

Physical and Cognitive Processes Affect RT Training

Improving RT performance often includes cognitive training techniques such as imagining/visualizing the start of a competition as well as physical training techniques such as resistance, stability, and plyometric power–building exercises for use during the start of a race. There have been several physical skills training techniques shown to help improve RT for all types of skaters (e.g., hockey skaters, speed skaters, figure skaters). For instance, Bower et al. (2010) found that the slide-board stride count, as well as a vertical-jump height test, were the best predictors of skating acceleration and RT speed. There are examples of mental skills training techniques that enhance RT performance. For instance, Ungerleider (1985) described the importance of imagery and visualization techniques for enhancing Olympic athlete performance, including RT, and Munzert (2009) described the specific role of imagery and mental representations on enhancing motor performance, including RT performance. Arvinen-Barrow, Weigand, Hemmings, and Walley (2008) describe the combination of both physical and mental training techniques for skaters. For example, Arvinen-Barrow et al. (2008, p. 135) detail ''cognitive specific (CS), motivational general-arousal (MG-A), and motivational general-mastery (MG-M) imagery'' types of training used during simulations of synchronized skating competitions.

Energy Expenditure and Overtraining

Recently, Holmes and Calmels (2008) reviewed the use of mental imagery in sports, including the role of mirror neurons during motor learning, and suggested that observational learning, such as a video screen showing images of an event arena or of a race taking place, is more beneficial than mental rehearsal, such as imagining first-person experiences of a race, when an athlete participates in RT training. For example, in the case of RT training at the start of the race, cognitive and physical techniques would be combined, such as mentally observing oneself at the start of a race, about to push off, while practicing a particular physical technique such as simulating the beginning push-off.

Holmes and Calmels (2008) also suggest that athletes maintain a balance between physical and mental training and warn about fatigue and potential injury due to physical or mental overexertion during training. Whereas energy expenditure is greater during physical training than during mental training simulations in a laboratory setting, there are suggestions that mental energy expenditure may lead to fatigue similar to physical energy expenditure, as reflected in changes in heart rate variability and other cardiorespiratory measures (Buchheit et al., 2006; Keytel et al., 2005; Pettitt, Pettitt, Cabrera, & Murray, 2007). Similarly, Nederhof, Zwerver, Brink, Meeusen, and Lemmink (2008) described the processes in which excessive physical or mental energy expenditure could lead to overtraining syndrome or nonfunctional overreaching. Providing active and ongoing feedback about physical and mental training processes is one of the major goals of the biofeedback-enhanced RT training program.

Yearly Training Plan

The coaches of the Canadian Olympic Speedskating Team, along with expert consultants, established a yearly training plan (YTP) to ensure that the athletes achieve measurable improvement in areas such as sprints, speed power, speed endurance, and endurance training. For the series of yearly training programs described in this article, the RT training was conducted at the end of 2008 and the end of 2009 leading up to the 2010 Vancouver Olympic Games. The RT program was introduced after many other sport psychology interventions had been completed as part of an extensive program that included completing the following:

1. Mental skills cognitive-behavioral training workbooks consisting of 22 modules
2. Mental skills log books designed to increase both mindfulness of athletes and the transfer of mental skills to improve the quality of training sessions during sprints, speed power drills, speed endurance practice, and endurance training
3. Cognitive surveys including the Ottawa Mental Skills Assessment (OMSAT), Rest and Recovery Profile (RESTQ-S), Competitive State Anxiety Scale (CSAI-2), and the Test of Attentional and Interpersonal Style (TAIS)
4. Medical and physical fitness tests, including blood tests and electrocardiograms

Biofeedback RT Program for Elite Speed Skaters

Modern biofeedback approaches for enhancing elite athlete performance have been described by Wilson, Peper, and Moss (2006), who built on the work of Bruno De Michaelis' ''Mind Room,'' used for training the world famous AC Milan soccer team. The particular biofeedback approach described in this article for enhancing RT training is part of a larger biofeedback program that included stress testing and training to develop competencies in self-regulation of heart rate variability (HRV), muscle tension (EMG), respiration, heart rate (HR), skin conductance (SC), and skin temperature (ST) in addition to alpha training (using electroencephalography [EEG]). For example, all of the athletes were given both a psychophysiological stress and an EEG test described by Wilson et al. (2006) to evaluate individualized responses to stress. Training sessions were conducted each week in both the physiology and the EEG program. A competency-based approach prevailed until each athlete developed automaticity with each skill area (e.g., HRV, EMG, SC, ST, and alpha EEG training).

This article focuses on the speed-training aspects of the program, especially when RT training occurred at least twice a week. RT training continued right up to the day of Olympic competition at the 2010 games.

Figure 1. Synchronizing and foot switch devices.

Method

Participants

Ten male athletes affiliated with Speedskating Canada volunteered for the training at the National Training Center in Montreal, Canada. During the 5-week RT training program aimed at improving RT performance in the 500-meter sprint events, each athlete completed at least 600 RT training trials, for a group total of 6,000 measurements of RT trials. The athletes had a mean age of 23.4 years and ranged in age from 18 to 28 years. The ethnic composition of the participants was 95% Caucasian, with one individual of Afro-Caribbean ethnic heritage. Mean (M) and standard deviation (SD) for height, weight, and body mass index (BMI) for the men were as follows: height, $M = 70.7$, $SD = 6.1$ inches; weight, $M = 165.2$, $SD = 13.5$ pounds; and BMI = 23.2 kg/m^2, respectively. All of the participants were normotensive and free of disease. All participants refrained from medication use, depressant use (e.g., alcohol), and stimulant use (e.g., smoking cigarettes or consuming caffeine) 3 hours before any testing and training.

Procedures and Equipment for RT Training

The RT training protocol was designed in collaboration with expert equipment engineers of a commercial biofeedback equipment provider (e.g., Thought Technology Ltd. in Montreal, Canada, using a FlexComp Infiniti encoder with BioGraph Infiniti software). Measurements of RT were made using a synchronizing device (e.g., TT-AV Sync, audio/visual device) that allowed accurate measurement to within less than .5 milliseconds of synchronized responses during RT training. During simulations of the start of a race, athletes must hold steady on the ice as they prepare to start the race. The measurement protocol was therefore designed to record activation of a foot pedal device with the activation logic reversed so that responses were recorded when the pedal was released rather than depressed (see Figure 1). This allowed the athletes to respond in a way similar to their actual starts on the ice. Using the synchronizing device also made it possible to record synchronous physiological signals such as brain activity (EEG), muscle activity (EMG), and other physiological signals (SC, ST, HR, and breathing), which could be used for feedback training (Buchheit et al., 2006; Keytel et al., 2005; Pettitt et al., 2007; Wilson et al., 2006). Note that the RT training sequence closely followed the learning of competencies in other biofeedback and EEG training aspects of the overall program. Consequently, the scope and sequence of the RT training and other parts of the program appeared seamless between the two.

Each athlete repeatedly simulated the process of starting a race. Specifically, the RT training protocol called for three sets of 10 trials, for a total of 30 simulated starts. The trainee viewed a computer monitor that displayed images of other speed skaters at a starting line during international competition, rather than a first-person point of view that the skater would normally see by looking down at the ice and/or the toe of a skate. Another computer monitor was used to display information to the coach (see Figures 2a and 2b). Simulated arena crowd noise was also played continuously during the RT training protocol. The RT protocol was designed to train increased corticospinal and somatosensory communication in anticipation of a starting line scenario, rather than to train increased physicality during the starts, because physical training (e.g., strength and endurance training) occurred during other parts of the training program (Kida et al., 2004; Leocani et al., 2000).

A trial (e.g., simulated start) was presented every 20 seconds. This parameter was chosen to keep the pace of the session high while allowing athletes to recover before resuming their position for the next trial. The audiovisual presentations involved (a) a warning in the form of the word *Ready* on the monitor (presented so that the coach could call out ''ready,'' as do starting judges in actual

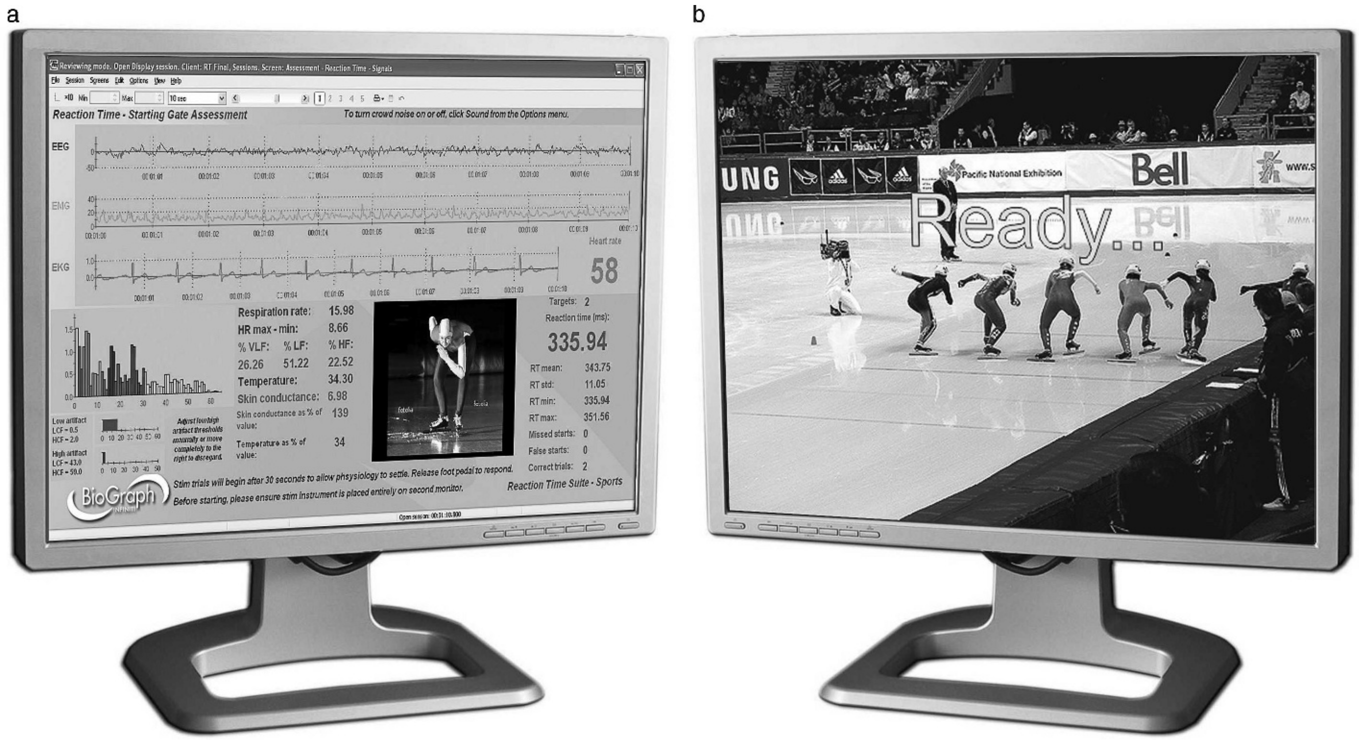

Figure 2. (a) Coaches' monitor. (b) Athletes' monitor.

competition) (b) followed by a start tone 2 seconds later, prompting the athlete to release the foot pedal. RT results were displayed on the coach's monitor. The coach could choose whether or not to notify the athlete of their RTs for each trial or to wait until the mean reaction of several trials (Ariel, 1983; Zaichkowsky & Sime, 1982).

After completing a dry-land warm up, each athlete would perform three sets of 10 trials per session on 2 separate days of the week for 5 weeks, for a total of 10 training sessions. Alternating feet were used for bilateral training (five trials with the left foot and five trials with the right foot) in the natural skating start position for each athlete (see Figure 3). At the coaches' discretion, knowledge of results was given to each athlete as feedback in milliseconds after each RT trial (Sánchez & Gonzalez, 2010). In addition, session means were also given to let athletes know how they performed at the end of all trials.

Figure 3. Athlete at Olympic Training Center during reaction time training.

Results

The current article presents the results of a 5-week training program for enhancing (e.g., making faster) the RT performance. A repeated-measures analysis of variance (ANOVA) was performed assessing the relationship between training week and RT performance. Before proceeding with further analysis, a test of sphericity using Mauchly's W was performed, showing the expected nonsignificant result (W = .987). The results of the repeated-measures ANOVA showed that there was a significant effect of training week on the RT performance, $F(1, 9) = 679.2$, $p = .001$. Post hoc analysis showed a statistically significant difference between training Week 1 and training Week 5, $t(2) = 4.47$, $p = .04$, as well as a statistically significant difference between training Week 4 and training Week 5, $t(2) = 7.24$, $p = .01$.

The Table represents the RT medians for the men's team during a 5-week macrocycle in the 2009–2010 YTP. As this research is part of an ongoing special project sponsored by Own the Podium in Calgary, Canada, through Speedskating Canada, the final tabulation of the data will be published at a later date.

Table. Median group reaction time for each training week

	RT 1	RT 2	RT 3	RT 4	RT 5	RT 6	RT 7	RT 8	RT 9	RT 10
Week 1a, Day1	292.65									
Week 1b, Day2		288.65								
Week 2a, Day1			290.22							
Week 2b, Day2				289.65						
Week 3a, Day1					279.66					
Week 3b, Day2						283.79				
Week 4a, Day1							272.39			
Week 4b, Day2								262.91		
Week 5a, Day1									221.79	
Week 5b, Day2										211.35

Note. RT = reaction time.

Figure 4 represents the medians of the group RTs during the 5-week macrocycle in the 2009–2010 YTP. As described in the results above, there is a visible difference in RT between the start of the training during Week 1 and Week 5. The largest absolute reduction in RT occurred between the beginning of Week 4 and the beginning of Week 5, where the partial eta-squared indicator of effect size was significant, $F(1, 9) = 754.2$, $p = .001$, partial $\eta^2 = .98$.

Discussion

The aim of the RT training was to better prepare athletes for the 500-meter sprint events at the 2010 Vancouver Olympic Games. One of the first applied sport psychologists to study athlete RT performance was Coleman Griffith (1930). He began testing football and basketball players at the University of Illinois using a ''Reaction Time'' machine. Griffith (1930) investigated varying apparatuses for RT testing in relation to muscular load, tension, and relaxation; different stimuli such as sound, light, and pressure; and tests for mental alertness with athletes. Subsequently, Freeman (1933) discovered that submaximal muscular tension in the form of a relaxed preparatory set or pre–start routine could facilitate improvements in RT. For more than three quarters of a century, sports researchers have found that RT training could improve performance in speed and strength tasks (Johnson, 1928), which explains why so many athletes today engage in a combination of physical and mental training, including RT training (Gould, Weinberg & Jackson, 1980; Jacobsen, 1932). In contrast with physical training alone, in which muscle fatigue would reduce technical efficiency and accuracy, the minimal muscle tension levels accompanying RT training in a laboratory would help prime coordinated hand and foot movements (Johnson, 1928). In particular, biofeedback techniques accompanying (Zaichowsky & Takenaka, 1993) cognitive and behavioral rehearsal can act to lower sensory thresholds of the athlete and facilitate automaticity of performance in a wide variety of motor tasks (Ripoll, 1991).

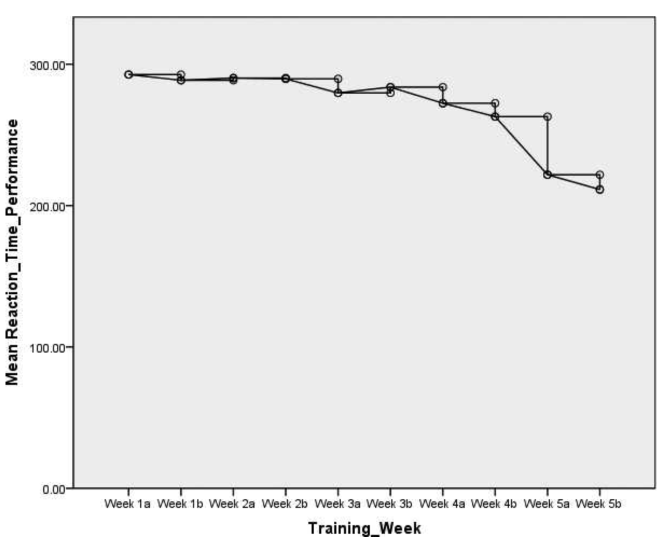

Figure 4. Median group reaction time for each training week. Note: training week for reaction time was part of a larger training program.

The most dramatic finding from the RT training was the effect of training between Week 4 and Week 5. In particular, the training revealed an effect after only 4 weeks of training. Future research (e.g., randomized control trials) will be necessary to reveal the mechanisms of the training effect. Speculation includes mechanisms related to sensorimotor automaticity development (Ashby, Turner, & Horvitz, 2010; Grol, de Lange, Verstraten, Passingham, & Toni, 2006; Repp, 2002). For example, Ashby et al. (2010) suggest that neural processes related to the sensorimotor striatum are involved in automaticity and possibly RT learning. Ongoing investigations are necessary to uncover the complex nature of automatic learning in athletes.

The goal of the RT training program was to prepare each individual skater for personal best performance under the pressure and on demand for the Olympic Games. As proof of the RT training effectiveness, the Canadian short-track speed-skating team achieved its goals both from a sprint perspective and also from a team perspective. First from a sprint perspective, the men's team brought home 1 gold and 1 bronze medal, whereas the women's team (not reported in this article) earned 1 silver medal and a fourth place in the 500-meter sprints. In addition, from a team perspective, the men's team won the team relay gold whereas the women brought home the silver in the team relay. The biofeedback RT training was an integral module within the overall sport psychology Speedskating Canada ''Mind Room'' program.

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