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Human Kinetics
ORIGINAL INVESTIGATION

Positive Effects of Augmented Feedback to Reduce Time on Ground in Well-Trained Runners

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Context: Successful elite sprint to long-distance runners are known to have shorter ground-contact time (GCT) than their less successful counterparts. ***Purpose:*** To investigate whether augmented feedback (aF) about GCT can reduce the time on ground (TOG) per minute in long-distance runners and, if so, whether this reduction improves running performance. ***Methods:*** Thirty well-trained runners were allocated to 3 groups. The intervention group (IG) received visual aF about their GCT during 8 high-intensity interval sessions in the 4-wk training period and were instructed to minimize GCT. The 1st control group (CG1) trained with the IG but was not given any feedback. The 2nd control group (CG2) followed their own training routine. Data were obtained pre- and postintervention for all 3 groups. The dependent variable was TOG per minute, computed from step frequency and GCT. ***Results:*** The IG significantly reduced TOG ($P = .043$, –1.7%, 90%CL –3.1;–0.3) and improved their mean 10 × 400-m performance time ($P < .001$, –1.5%, 90% CL –1.9;–1.1). In contrast, the 2 control groups revealed unchanged values, indicating that normal high-intensity training and an individualized routine without aF were not able to reduce TOG. The fact that CG1 received the same instructions and participated in the same training sessions as the IG underlined that aF was crucial to reduce TOG. ***Conclusions:*** The provision of aF about GCT seems to be a promising approach that should be considered during training practice of well-trained runners.

Keywords: body-worn sensor, athletics, training intervention, real-time

Oftentimes athletes' perception derived from intrinsic feedback is not sufficient to adequately judge their movement execution.[1,2] Therefore, specific information from an external source is necessary to gain a better understanding of a particular movement pattern or of certain aspects of a movement. Information about one's own performance provided by an external source is called augmented feedback (aF). The use of aF has previously been shown to improve motor performance in the short and long term.[2–4] However, aF only seems beneficial when it provides information in addition to subjective perception.[1,5] It has been reported that aF is particularly efficient for fast movements, because the faster the movement velocity and the smaller the difference between movement sequences, the more difficult it is to differentiate between good and less-good performances based on task-intrinsic sensory feedback.

It has been previously demonstrated that ground-contact time (GCT) is a relevant performance variable in running, as it is the only period when large amounts of muscle force are generated and transmitted to the support surface.[6–10] A shorter GCT has been associated with faster running time and greater force application during shorter GCT.[8,9,11] Shorter GCT seems to be more energy efficient due to the better use of elastic energy.[8] Related to this, 90% to 96% of the variance in leg stiffness can be explained by GCT.[6] In a study by Paavolainen et al,[9] top athletes and lower-performing athletes performed a 10,000-m run on a 200-m indoor track. Participants were asked to accomplish the time trial as fast as possible, except for 5 predetermined constant-velocity laps for kilometers 1, 3, 5, 7, and 10. During these constant-velocity laps, the top runners had significantly shorter GCT and braking and propulsion phases than the lower-performing runners. Moreover, shorter mean GCT of the constant-velocity lap correlated significantly with 10,000-m performance time.

Based on these observations, it seems worthwhile to focus on GCT for competitive runners to improve overall performance. However, GCT in competitive running lasts only about 100 to 250 milliseconds (depending on the speed) for each step.[12,13] Hence, GCT is almost impossible to judge without the help of an external source. Therefore, the primary purpose of this study was to investigate whether aF about GCT can reduce time on ground (TOG) per minute in well-trained long-distance runners. Furthermore, as the secondary aim we evaluated whether these reductions in TOG lead to improved running performance.

Methods

Participants

Thirty healthy participants in the late preparation phase for a 5- and 15-km race were recruited (age 31.0 ± 7.5 y, height 1.74 ± 0.1 m, weight 65.2 ± 10.2 kg; 12 women). All are well-trained runners of similar level from a regional training group who undertake regular track training and participate in long-distance track and field or mainly flat road races. On average, the participants had 11.3 ± 7.5 years of running experience and 409 ± 182 minutes of weekly training practice (Table 1). Written informed consent was obtained from all participants after familiarization with the study procedure, which was approved by the internal review board of the Federal Office of Sport, in the spirit of the Helsinki Declaration.

Research Design

The study consisted of a 3-group randomized controlled trial with baseline and follow-up measurements. Over a 4-week period, the intervention group (IG) and the first control group (CG1)

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Table 1 Characteristics of Participants, Mean (SD)

	IG, n = 10	CG1, n = 10	CG2, n = 10	*F*	*P*
Age, y	28.6 (2.5)	30.8 (6.9)	28.9 (6.6)	0.430	.655
Gender (Female)	4	4	4	0.370	.694
Height, m	1.75 (0.1)	1.75 (0.1)	1.72 (0.1)	0.167	.847
Weight, kg	66.3 (11.6)	66.1 (10.6)	60.4 (10.4)	0.893	.421
V_{1000}, m/s	5.34 (.69)	5.27 (.54)	5.25 (.58)	0.064	.938
Running Experience, y	10.3 (4.8)	9.1 (6.1)	12.4 (9.6)	0.545	.586
Competing Distance, km	12.0 (4.8)	12.5 (4.5)	12.0 (4.8)	0.039	.962
Training Hours,[a] min/wk	415 (179)	390 (158)	434 (204)	0.431	.651
Endurance training	382 (180)	348 (158)	393 (220)	0.529	.591
interval running	58 (36)	57 (34)	46 (35)	0.829	.439
Strength training	33 (26)	42 (32)	42 (31)	1.30	.278

Abbreviations: CG1, 1st control group; CG2, 2nd control group; IG, intervention group; V_{1000}, average speed over 1000-m time trial.
[a]Total training hours per week, including the intervention sessions, derived from training diaries.

undertook identical training with 2 interval sessions per week on a synthetic outdoor track. During this training intervention, the participants in the IG received aF about their GCT after each run with the instruction to minimize GCT in the following run, and those in the CG1 had the same training and instructions as the IG, but without aF. The second control group (CG2) did not participate in any training with the IG or CG1. This study design was chosen to exclude the possibility that neither the instructions (CG1) nor the interval training per se (CG2) was primarily responsible for affecting the adaptations in GCT.

Methodology

Prestudy, Baseline, and Follow-up Measurements. A prestudy measurement was made to determine maximal mean speed over 1000 m (V_{1000}). Within 1 month prior to the start of the study, all participants performed a maximum 1000-m time trial on a synthetic outdoor track.

Baseline and follow-up measurements were made to determine biomechanical and physiological parameters. These measurements took place in the laboratory on a treadmill (Venus, h/p/cosmos sports & medical GmbH, Nussdorf-Traunstein, Germany) to ensure exactly the same test settings at baseline and follow-up. All participants were familiar with running on a treadmill, which was validated and certified at 12 to 24 km/h. The environmental conditions in the laboratory were identical for all measurements, with an average temperature of 22°C (minimum 19°C, maximum 24°C) and humidity of 49% (minimum 44%, maximum 55%). On the test day, the participants warmed up individually by running outdoors for 10 minutes before performing a standardized warm-up on the treadmill that consisted of 2 minutes at 60% V_{1000}. Thereafter, the participants performed the 1000-m at 80% of their individual V_{1000} with 1% inclination. This protocol was chosen according to experienced running coaches (eg, national coach) because it approximately represents the running pace of 15- to 20-km competitions. The test conditions were the same for all participants, who were asked to run as normally as possible. After the warm-up and right after the 1000-m at 80% V_{1000}, blood lactate was obtained from participants' earlobes (Lactate Pro Analyzer, Carlton, Australia), and their rating of perceived exertion was assessed using the 6-to-20 Borg scale.[14] During the entire 1000 m, heart rate was measured using a chest strap (Suunto t6c, Suunto, Valimotie, Finland), and GCT, swing time, and step frequency were measured using a portable inertial measurement unit (Axiamote, Axiamo, Biel, Switzerland). The accuracy of the sensor in the assessment of the GCT has recently been demonstrated with a 1.3% error rate compared with the criterion measure.[13] It is 3.8 × 3.7 × 0.8 cm in size and 13 g in weight and consists of a 9-axis MotionTracking™ device, recording accelerometer data with a full-scale range of ±16 *g* and a sampling rate of 1000 Hz. A device was tightly attached to the shoelaces of each foot. Participants wore the same cushioned running shoes during baseline and follow-up measurements. After the baseline measurements, they were randomly assigned to the IG, CG1, or CG2, presumably based on an equal gender distribution.

Training Intervention. The experimental protocol consisted of 2 supervised high-intensity interval sessions per week on an outdoor 400-m synthetic track over a 4-week period, resulting in a total of 8 interval-training sessions (Table 2). The content of the training intervention was decided in close collaboration with the national coach for middle- and long-distance running. Only the IG and CG1 participated in these supervised interval-training sessions, and they attended these sessions as a group. Participants were instructed to always run with the self-paced highest possible intensity and preferably at a similar intensity throughout a training session. Preceding warm-ups were done individually, and footwear could be varied between training sessions. In order to equip both groups identically, all participants wore a sensor on the shoelaces of each shoe during all supervised training sessions. Sensor control and data transmission were established on participants' own tablets (Samsung Galaxy Tab 4, Samsung Corp, Seoul, South Korea) via Bluetooth. Only the IG received aF visualized on tablet screens, which was provided during the regular rest periods between intervals. As aF, the mean GCT of 1 interval run was displayed as a bar and an absolute number, next to the information of the previous run(s) (Figure 1). Verbal instruction to the IG and CG1 was given to minimize the GCT in the following run but to maintain the speed of the previous run(s). No other instructions such as a strategy were provided to achieve the desired outcome. Split times and Borg values were assessed for each interval run.

The participants in the IG and CG1 were monitored for signs of problems related to the training load of the intervention. This was done using a short version of the recovery-strain questionnaire prior to each interval-training session.[15] The participants were asked about their perception of pain, soreness, bad mood, and sleeping troubles

Table 2 Experimental Protocol

Week	Measurement	Group	Content	Outcome
–4	Prestudy	IG, CG1, CG2	Maximal 1000-m time trial	V_{1000}
1	Baseline	IG, CG1, CG2	1000 m at 80% V_{1000} (on treadmill)	TOG, GCT, SF, swing time, HR, BL, Borg
2	1	IG, CG1	10 × 400 m, 90-s R (aF)	Mean 10 × 400-m performance time
	2	IG, CG1	7 × 800 m, 120-s R (aF)	
3	3	IG, CG1	6 × 1000 m, 150-s R (aF)	
	4	IG, CG1	8 × 600 m, 100-s R (aF)	
4	5	IG, CG1	7 × 800 m, 120-s R (aF)	
	6	IG, CG1	6 × 1000 m, 150-s R (aF)	
5	7	IG, CG1	8 × 600 m, 100-s R (aF)	
	8	IG, CG1	10 × 400 m, 90-s R (aF)	Mean 10 × 400-m performance time
6	Follow-up	IG, CG1, CG2	1000 m at 80% V_{1000} (on treadmill)	TOG, GCT, SF, swing time, HR, BL, Borg

Abbreviations: aF, provision of augmented feedback to intervention group; BL, blood lactate; Borg, rating of perceived exertion; CG1, 1st control group; CG2, 2nd control group; GCT, ground-contact time; HR, heart rate; IG, intervention group; R, rest time between interval runs; SF, step frequency; TOG, time on ground per minute; V_{1000}, average speed over 1000-m time trial.

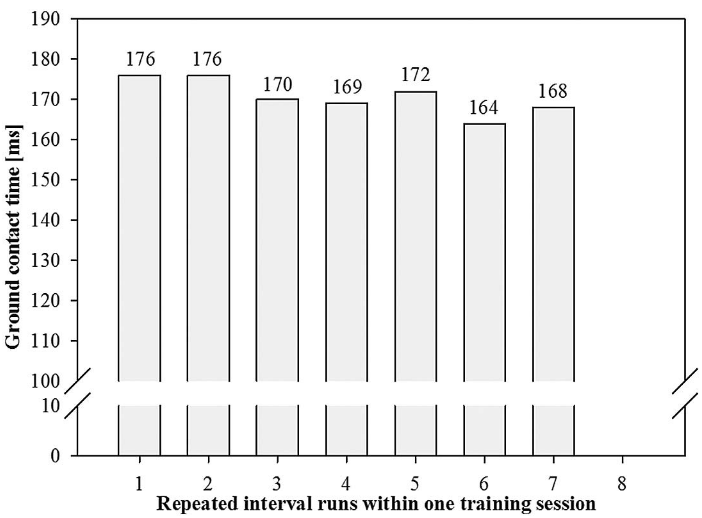

Figure 1 — Example of 1 participant during the 8 × 600-m interval session running at approximately 5.6 m/s. Each bar represents the augmented feedback about the mean ground-contact time of a 600-m run.

during the previous 3 days and nights. The answers were constantly reviewed to identify potential overtraining symptoms.

Apart from the 2 track training sessions each week, it was not possible to standardize the entire training procedure. To ensure a training intervention in a natural setting, the unique sample of well-trained athletes followed their normal individualized training routine. To control for the training program during the experimental period, participants from all 3 groups kept a predetermined training diary to record all their physical activities.

Data Analysis

GCT is closely related to step frequency and should therefore not be investigated in isolation. This is, for instance, stressed by Padulo et al,[16] who demonstrated positive correlations between step frequency and speed and negative correlations between GCT and speed. Hence, to avoid a bias caused by changes in step frequency, TOG per minute was chosen as the primary outcome variable.[8] To compute TOG, the mean step counts per minute was multiplied by the mean GCT. The TOG per minute was compared between baseline and follow-up measurements obtained on the treadmill. In addition, to investigate whether reduced TOG led to improved running performance (secondary outcome variable), mean 400-m times of the 10 × 400-m interval training on the outdoor track were compared between the first and last training weeks. Data on TOG were analyzed between and within the IG, CG1, and CG2, and data on mean 10 × 400-m performance time were evaluated for the IG and CG1.

Statistical Analysis

Statistical analysis was conducted using Microsoft Excel (2011) and SPSS 22.0 (IBM, Inc, Armonk, NY, USA). Data are presented as mean ± SD if not otherwise indicated. Normality of the data was assumed because the ratio of skewness to the standard deviation of skewness did not exceed ±2.0. One-way analyses of variance and independent *t* tests were used to test for baseline differences between groups. To evaluate the intervention effects on TOG and mean 10 × 400-m performance time, marginal means model analyses were conducted with group (IG, CG1, CG2) and intervention (baseline, follow-up) as main effects and group × intervention as an interaction effect.[17] Planned contrasts were carried out to determine between-groups differences. Furthermore, effect sizes are presented as partial eta-squared values. In addition, to make inferences about true values of the effect of aF about GCT on TOG, the uncertainty in the effect was expressed as 90% confidence level (CL) and as likelihood that the true value of the effect represents substantial change (harm or benefit).[18] The smallest worthwhile change in TOG was assumed to be a reduction of 1.2%. This was calculated as 0.2 multiplied by the between-participants SD expressed as a coefficient of variance.[18,19] In terms of mean 10 × 400-m running performance, the smallest worthwhile change in mean 10 × 400-m time was 1.8%. Quantitative chances of substantial positive, trivial, or negative changes were subdivided as follows: <0.5%, almost certainly not; 0.5% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possibly; 75% to 95%, likely; 95% to 99.5%, very likely; and >99.5% almost certainly.[20] If the chances of having positive and negative changes were both >5%, the true difference was deemed unclear.

Results

No baseline differences between groups were revealed for age, height, weight, V_{1000}, competing distance, and previous running experience (Table 1). Even more important, there were no between-groups differences regarding TOG and mean 10 × 400-m performance time at baseline. In addition, the evaluation of the training diaries revealed no between-groups differences in terms of training hours, intensities, and content during the 4-week intervention.

In the marginal means model on TOG, a significant interaction effect was observed for group (IG, CG1, CG2) × intervention (baseline, follow-up) ($F_{2,27} = 4.284$, $P = .024$, $\eta_p^2 = .24$), but neither a group nor an overall intervention effect occurred (Table 3). Planned contrasts revealed that the IG could significantly reduce TOG ($t_{27} = -2.869$, $P = .008$) compared with the 2 control groups, whereas no changes occurred between the CG1 and CG2 ($t_{27} = -0.210$, $P = .835$; Figure 2[a]). The magnitude-based-inference analyses revealed a 76% chance of a beneficial intervention effect in the IG and a 91% and 90% better chance to decrease TOG compared with the CG1 and CG2, respectively (Table 4). The IG's step frequency ($P = .045$, −1.5%, 90%CL −2.7;−0.4) and heart rate ($P = .031$, −2.6%, 90%CL −4.4;−0.7) were significantly lower

Table 3 Summary of Measured Parameters Before and After the Intervention, Mean (SD)

	IG n = 10		CG1 n = 10		CG2 n = 10	
	Baseline	**Follow-up**	**Baseline**	**Follow-up**	**Baseline**	**Follow-up**
Treadmill parameters						
TOG, s/min	37.7 (2.8)	37.0 (2.5)*	37.9 (1.3)	38.3 (1.4)	38.0 (2.8)	38.3 (2.7)
GCT, ms	212.6 (21.7)	211.9 (20.7)	209.0 (14.5)	212.1 (11.8)	207.9 (15.9)	212.9 (18.1)
SF, steps/s	2.96 (.13)	2.92 (.13)*	3.03 (.18)	3.02 (.17)	3.05 (.18)	3.00 (.19)
swing time, ms	463.7 (18.7)	474.5 (18.2)*	452.5 (26.7)	453.2 (30.2)	455.7 (27.7)	455.6 (36.2)
heart rate, beats/min	154.6 (8.8)	150.7 (8.6)*	153.8 (6.6)	152.4 (7.4)	149.5 (9.8)	146.9 (8.5)
BL, mmol/L	2.4 (0.8)	2.3 (0.8)	2.4 (1.3)	2.3 (0.9)	2.7 (1.4)	2.5 (1.5)
Borg, 6–20	13.6 (1.1)	13.1 (1.1)	12.9 (1.5)	12.7 (1.3)	12.9 (1.2)	12.5 (1.2)
Performance parameters						
10 × 400-m time, s	79.1 (7.3)	78.0 (7.2)*	78.8 (7.3)	78.6 (7.3)		
Borg, 6–20	17.5 (0.7)	17.4 (0.9)	16.9 (1.9)	17.4 (1.7)		

Abbreviations: BL, blood lactate; Borg, rating of perceived exertion; CG1, first control group; CG2, second control group; GCT, ground-contact time; IG, intervention group; SF, step frequency; TOG, time on ground per minute.
*$P < .05$: significant intervention (baseline, follow-up) difference within group.

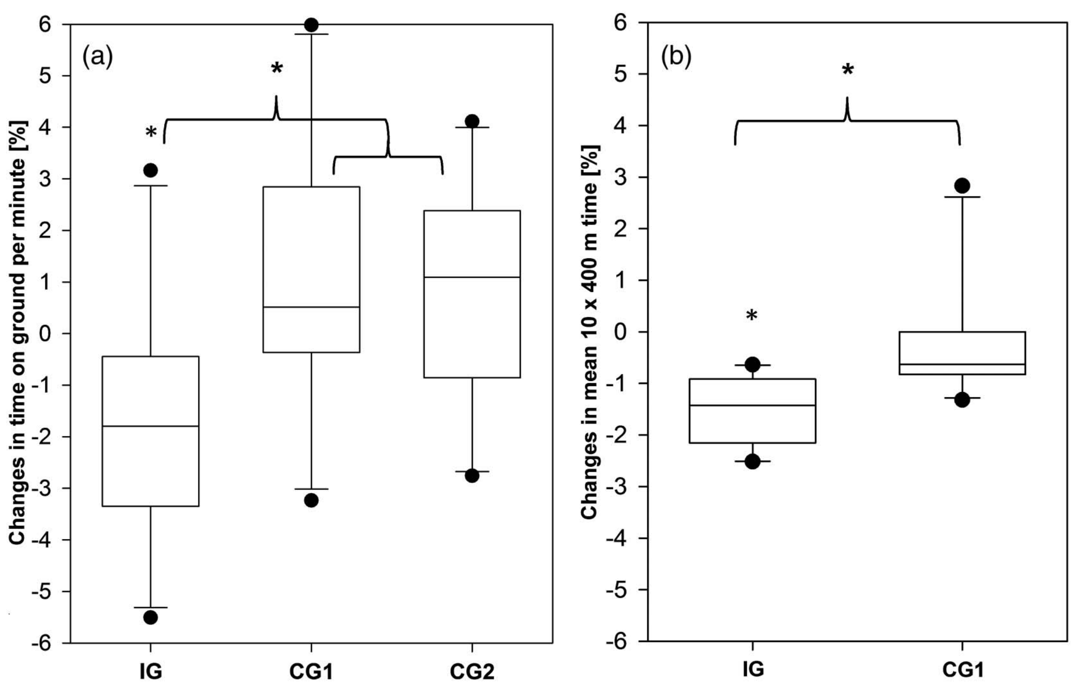

Figure 2 — (a) Relative changes in time on ground per minute and (b) relative changes in the mean 10 × 400-m running time between baseline and follow-up measurements. IG indicates intervention group; CG1, first control group; CG2, second control group. *$P < .05$: significant intervention (baseline, follow-up) difference between and/or within group.

Table 4 Magnitude-Based-Inference Analyses Within and Between Groups

		Δ% (90% CL)	Change % positive	% trivial	% negative	Qualitative inference
Time on ground per minute						
IG	Post–Pre	−1.7 (−3.1;−0.3)	76	24	0	Likely beneficial
CG1	Post–Pre	1.0 (−0.5;2.6)	1	57	42	Possibly trivial
CG2	Post–Pre	0.8 (−0.4;2.1)	1	70	29	Possibly trivial
%Δ	IG–CG1	−2.8 (−0.8;−4.8)	91	8	0	Likely beneficial
%Δ	IG–CG2	−2.6 (−0.8;−4.4)	90	10	0	Likely beneficial
Mean 10 × 400-m performance time						
IG	Post–Pre	−1.5 (−1.9;−1.1)	10	90	0	Likely trivial
CG1	Post–Pre	−0.2 (−0.9;0.5)	0	100	0	Trivial
%Δ	IG–CG1	−1.3 (−2.1;0.5)	13	87	0	Likely trivial

Abbreviations: CG1, first control group; CG2, second control group; CL, confidence level; IG, intervention group.
Note: Smallest worthwhile change (SWC) in time on ground per minute = 1.2%; SWC in mean 10 × 400-m performance time = 1.8%.

and the swing time ($P = .028$, +2.3% with 90%CL 3.3; 18.4) significantly longer during the follow-up than during the baseline measurement (Table 3).

Considering the mean 10 × 400-m performance time, the marginal means model detected a significant intervention (baseline, follow-up) ($F_{1,18} = 14.68$, $P = .001$, $\eta_p^2 = .45$) and interaction effect ($F_{1,18} = 8.26$, $P = .010$, $\eta_p^2 = .31$; Table 3). Planned contrasts revealed that the IG could significantly reduce 400-m time compared with CG1 ($t_{18} = 2.955$, $P = .008$; Figure 2[b]). However, the correlations between changes in TOG and changes in performance time were nonsignificant ($r = .397$, $P = .142$, and $r = .201$, $P = .275$, for the IG and CG1, respectively).

During the 4-week training intervention, the runners in the IG and CG1 completed 7.6 and 7.3 of the 8 scheduled training sessions, respectively. The participants performed the interval runs in a session at steady paces, with overall coefficients of variation of 1.6% (0.9–2.2%) and 1.5% (0.6–2.6%) in the IG and CG1, respectively. Moreover, changes in the variables TOG and mean 10 × 400-m performance time were not related to baseline GCT, V_{1000}, or participant body weight, as no significant correlations were found.

Discussion

Recently, aF has been shown to evoke better improvements in performance than the same training without feedback.[2,3,21] The findings of the present study are in line with these observations, showing superior results in the IG that received aF compared with CG1 and CG2 that did not receive aF. Although the participants in CG1 followed the same training sessions and received the same instructions as the IG, they were not able to reduce TOG. Instead, CG1 showed unchanged TOG values at follow-up similar to those of CG2, who did not attend any training sessions with the IG. The reason for this may be related to the fact that the runners themselves were not able to properly perceive their GCT. A previous study showed that high-level tennis players could not judge whether a tennis serve was faster or slower than the previous serve.[2] By providing this information in the form of aF, players enhanced service speed. Therefore, aF seems necessary to adequately adjust movement execution. Related to this, it was previously shown that aF only enhances learning and performance when it provides essential information in addition to the sensory task-intrinsic feedback.[1,5] The present study supports this assumption. The chances of a true reduction in TOG between the IG and CG1 and the IG and CG2 were 90% and 91%, respectively. Hence, aF about GCT between runs was likely to result in a beneficial reduction in TOG. We therefore conclude that displaying the GCT after each run added essential information, as the movement speed was so high that sensory feedback was not sufficient to reliably perceive GCT. Furthermore, the results showed that providing feedback about GCT induced significant changes in running technique. Even a small change in GCT had an impact on step frequency and swing time. Athletes who were able to decrease GCT tended to show reduced step frequencies and prolonged swing times. Moreover, the reduction in TOG did not lead to enhanced physiological demands, as in previous studies using aF during running.[22,23] On the contrary, heart rate was significantly reduced at follow-up and blood lactate and ratings of perceived exertion tended to be lower in the IG.

The present study demonstrated that despite the same instruction to reduce GCT, only the IG achieved the aim of reducing TOG, whereas the 2 control groups revealed unchanged values. The question now is how this adaptation relates to performance. In previous studies, the variables that were fed back had to be maximized—for instance, the service speed in tennis,[2] force during leg presses,[24] or jump height[3,25]—or a movement error had to be minimized, such as a reduction in jump-landing force.[26] In contrast, minimizing GCT/TOG to its limits is in all likelihood not beneficial and, rather, follows an optimum function instead of a minimizing function. Consequently, the authors were not sure whether training with aF would be beneficial in this case, although it is known that elite runners demonstrate shorter GCT than nonelite runners.[8,9,11] Hence, it was unclear if aiming for a minimized GCT would improve performance in well-trained runners. However, the mean 10 × 400-m times were significantly reduced in the IG with aF but not in CG1. Furthermore, the IG could significantly reduce 400-m time compared with CG1. Nevertheless, the correlations between reduction in TOG and performance improvement were nonsignificant. It might therefore be assumed that some participants in the IG could better transfer reduced TOG into enhanced running speed than others. This might further support the assumption that GCT/TOG follows an optimum function and not a minimizing function. In addition, the participants in the present study were well-trained runners in whom there may be only small physiological gains after a training period of only 4 weeks. Consequently, the finding of a 1.5% reduction in mean 10 × 400-m running time for the IG compared with the 0.2% reduction in CG1 might already be a relevant observation in well-trained runners.

It cannot be excluded that aF not only guided the athletes toward the best running strategy but also increased intrinsic motivation. In 2 recent studies that investigated the influence of aF about jumping performance, the immediate increase in jump height with aF and the reduction in performance as soon as aF was withdrawn was assumed to depend on predominantly motivational factors.[3,27] Therefore, positive long-term effects of aF might also be related to a more intense movement execution with aF, making each training session more efficient.[3] However, this might not be entirely transferable to the present study, in which the variable that was fed back was not the performance variable per se—for example, the time for a certain distance—but, rather, technical guidance. More important, as GCT/TOG might follow an optimum rather than a minimum function, increased intrinsic motivation seems to be less of an issue.

This is the first intervention study fully implemented in the existing training routine of well-trained runners to evaluate the effects of aF about GCT to reduce TOG and how this transfers to running performance. The participants trained during their usual running-training hours and had no extra exercises to accomplish, such as strength training or jumps.

Practical Applications

The manipulation or "disturbance" of training by providing aF to the IG was trivial. From a functional point of view, the use of this relatively simple measurement technique "in the field" revealed promising training outcomes. The technology is easy to handle, does not hamper users during running, and is feasible in a whole training group. Alternatively, the athlete can simply use the technology independently during training to obtain aF. Moran et al[2] and Porter et al[28] highlighted the importance of external sources that can be used by athletes themselves, as in many sports disciplines the majority of practice is done without the coach.

Nevertheless, 4 limitations need to be addressed. First, we did not perform any retention assessments, nor did we test whether learning transferred to competition. Second, some people might counter that we did not apply a faded-feedback approach with a stepwise reduction in the provision of aF. However, as long as the underlying mechanism of how aF affects motor performance is not fully understood, best practices cannot be defined.[4] Given the inconclusive findings and recommendations in the literature on the frequency of aF and how this relates to the type of feedback and task complexity, we do not overemphasize this as a drawback. Third, one could object that performance improvement was not assessed in an isolated baseline and follow-up maximal test. However, it is known that motivational aspects should not be neglected, especially in maximal tests.[29] Therefore, it was not explicitly pointed out to the participants in the present study that the mean 10 × 400-m times in the first and last training weeks would be evaluated to quantify performance changes. However, they were always instructed to run with maximum intensity. Subsequently, enhanced motivation or altered focus of attention is unlikely to have altered intensity of task execution in any group. Finally, to investigate the effects of biomechanical changes on physiological variables, gas-exchange measurements might be recommended, yet in a review by Shephard,[30] measurement errors of about 5% for oxygen-uptake tests and slightly less for submaximal tests were quantified (eg, due to both preparation of the participant and equipment calibration). Based on the magnitude of these measurement errors and the high performance level of our runners, it would seem unlikely that applying gas-exchange measurements would have helped detect meaningful changes in the current study. Nevertheless, subsequent studies might consider this point to provide a more complete picture of the training adaptations.

Conclusions

The positive effects in the IG suggest that aF enabled the participants to shorten their TOG. No effect was observed in the control groups, underscoring the importance of aF. At the same time, mean 10 × 400-m running time was significantly reduced only in the IG. The provision of aF about GCT therefore seems to be a promising approach that should be considered for well-trained runners.

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