"Go" Signal Intensity Influences the Sprint Start

ALEXANDER M. BROWN[1], ZOLTAN R. KENWELL[1], BRIAN K.V. MARAJ[1,2], and DAVID F. COLLINS[1,2]

Human Neurophysiology Laboratory, [1]Faculty of Physical Education and Recreation, [2]Centre for Neuroscience, University of Alberta, Edmonton, Alberta, CANADA

ABSTRACT

BROWN, A. M., Z. R. KENWELL, B. K. V. MARAJ, and D. F. COLLINS. "Go" Signal Intensity Influences the Sprint Start. *Med. Sci. Sports Exerc.*, Vol. 40, No. 6, pp. 1144–1150, 2008. **Introduction:** Loud sounds can decrease reaction time (RT) and increase force generated during voluntary contractions. Accordingly, we hypothesized that the loud starter's pistol at the Olympic Games allows runners closer to the starter to react sooner and stronger than runners farther away. **Methods:** RT for the 100/110 m athletics events at the 2004 Olympics were obtained from International Association of Athletics Federations archives and binned by lane. Additionally, 12 untrained participants and four trained sprinters performed sprint starts from starting blocks modified to measure horizontal force. The "go" signal, a recorded gunshot, was randomly presented at 80–100–120 dB. **Results:** Runners closest to the starter at the Olympics had significantly lower RT than those further away. Mean RT for lane 1 (160 ms) was significantly lower than for lanes 2–8 (175 ± 5 ms), and RT for lane 2 was significantly lower than that for lane 7. Experimentally, increasing "go" signal intensity from 80–100–120 dB significantly decreased RT from 138 ± 30 to 128 ± 25 to 120 ± 20 ms, respectively. Peak force was not influenced by sound intensity. However, time to peak force was significantly lower for the 120 dB compared to the 80-dB "go" signal for untrained but not trained participants. When a startle response was evoked, RT was 18 ms lower than for starts with no startle. Startle did not alter peak force or time to peak force. **Conclusion:** Graded decreases in RT may reflect a summation-mediated reduction in audiomotor transmission time, whereas step-like decreases associated with startle may reflect a bypassing of specific cortical circuits. We suggest that procedures presently used to start the Olympic sprint events afford runners closer to the starter the advantage of hearing the "go" signal louder; consequently, they react sooner but not more strongly than their competitors. **Key Words:** REACTION TIME, MOTOR PROGRAM, HUMAN PERFORMANCE, STARTLE RESPONSE, AUDITORY PROCESSING

Reaction time (RT) is a critical aspect of many everyday tasks and competitive sports. For example, a rapid response would be vital for a pedestrian startled by the horn of an oncoming vehicle. In many competitive sports, minimizing RT can be the key to success, particularly in the sprint events of athletics where hundredths of a second can separate a first and second place finish. Thus, it was surprising to find that at the 1996 Olympic Games, there appeared to be a relationship between lane assignment and RT, such that RT progressively increased from lanes 1 to 8 (19); however, this discrepancy was not tested for statistical significance.

Sprint events in athletics at the Olympic Games are started with the commands "on your marks", "set," and the "go" signal delivered via speakers located behind each runner (personal communication from the International Association of Athletics Federations, or IAAF). The "go" signal is also delivered as a gunshot from a loud pistol fired by a starter positioned on the inside of the track closest to lane 1 (personal communication from the IAAF). According to OMEGA, the official time keepers of the Olympic Games, the "go" signal has been delivered through the speakers behind each runner since 1984 to avoid problems related to sound propagation (www.omegawatches.com/index.php?id=1090). However, Lennart Julin and Dapena (19) suggested that the discrepancies in RT in the 1996 data (described above) are consistent with delays related to the time required for sound to propagate from the starting pistol beside lanes 1 to 8, suggesting that the use of the loud gun remains problematic. Presently, we propose that the relationship between lane assignment and RT is due to sound propagation as well as the fact that runners closest to the starter will hear the "go" signal loudest as sound intensity decays in an inverse square relationship with distance. Experiments have demonstrated that RT is

Address for correspondence: David F. Collins, E-488 Van Vliet Centre, University of Alberta, Edmonton, Alberta, Canada T6H 1S1; E-mail: dave.collins@ualberta.ca.
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inversely related to "go" signal intensity when performing simple tasks (18). Auditory stimuli that evoke a startle response decrease RT even further (7,30). A startle is an involuntary response to an intense stimulus, one hallmark of which is an eyeblink ~30–60 ms after the stimulus (4). A louder "go" signal may also provide sprinters with other advantages. Loud sounds applied before maximal (13) and submaximal (3,15) execution of simple tasks can significantly increase peak force. The aforementioned experiments were typically performed using upper limb tasks with relatively few degrees of freedom. The influence of auditory stimulus intensity on the initiation of complex motor tasks, such as locomotion, is not known.

In the present study, we investigated the influence of lane assignment on RT for the sprint events in Athletics at the 2004 Olympic Games in Athens. We then tested experimentally the influence of the intensity of an auditory "go" signal on RT and the application of horizontal force during a sprint start in a group of 16 participants. We hypothesized that RT would decrease as the "go" signal intensity increased and that the occurrence of a startle response would decrease RT further. Additionally, we hypothesized that the peak horizontal force would increase and the time required to reach peak force would decrease during a sprint start as the "go" signal intensity increased. We further hypothesized that the occurrence of a startle would not influence the characteristics of the movement itself (peak force, time to peak) in accordance with previous findings (8,29) and the theory that the startle response is associated with the earlier release of a prepared motor program from subcortical structures (7,24).

METHODS

RT from the 2004 Olympic Games. RT for the sprint events were obtained from the IAAF archives (www.iaaf.org/oly04/results/byevent.html). Events included were all of the men's 100-m sprint and 110-m hurdles, as well as all of the women's 100-m sprint and 100-m hurdles. All RT were binned according to lane with a total of 375 out of a possible 407 used for the analysis. RT (n = 32) for runners who competed in the same lane more than once were not included in the analysis.

Experimental procedures. Twelve untrained (six men and six women, age 21.7 ± 2.7 yr) and four trained participants from the University of Alberta sprint team (all males, age 21.3 ± 3.3 yr) performed sprint starts from conventional starting blocks modified to measure horizontal force. The study was conducted with the approval of the University of Alberta Faculty of Physical Education and Recreation Research Ethics Board. Subjects provided informed written consent before participation. Participants performed practice starts (~2–5) to warm up and to become familiar with the experimental procedures. They were instructed to start as quickly and strongly as possible without anticipating the "go" signal. Untrained participants performed 60 sprint starts in a carpeted room and typically ran for a distance of ~10 m after leaving the blocks. Rest periods were incorporated, when needed, to avoid participant fatigue. Untrained participants typically rested for 1–2 min between starts. Trained sprinters performed 15 starts on an indoor track. They typically covered a distance of approximately 30 m after leaving the blocks and followed this with a rest period of 5 min before the next start. Each session lasted approximately 2 h for both untrained and trained participants.

Auditory stimuli. Standard starting commands ("ready" and "set") were delivered at 70 dB by computer through an amplifier (Realistic SA-10) and a 6-inch trumpet horn (Speco, SPC-10/4) placed beside the participant at head level approximately 30 cm from the ear. The "go" signal, a recorded gunshot, was randomly presented at 80, 100, or 120 dB. The intensities of all auditory commands

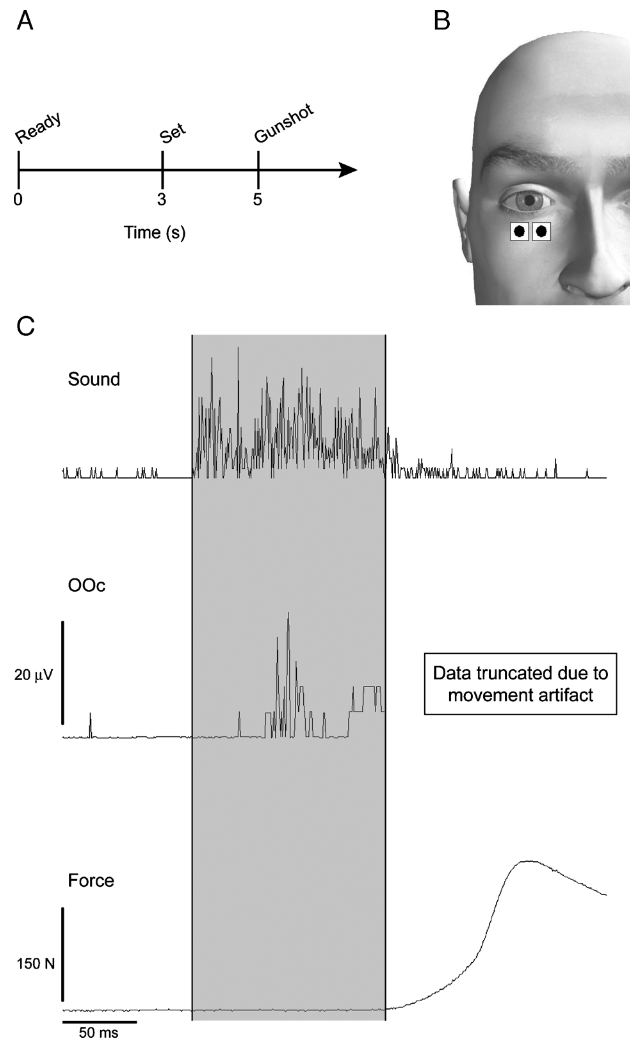

FIGURE 1—Experimental method and data analysis. *A*. The fixed timing of the commands delivered relative to "ready". *B*. EMG recording electrodes were placed over the right orbicularis oculi (OOc) as indicated by the *black circles*. A single ground electrode was placed over the cheek bone (not shown). C. Sound, force, and OOc EMG traces recorded during a single sprint start trial at 120 dB. "Go" signal and force onset are indicated by *horizontal lines*. The RT is the *shaded region*. A burst of EMG activity in the OOc about 60 ms after the "go" signal is associated with a startle response.

were calibrated using a sound level meter (Radioshack Digital Sound Level Meter 33–2055). The foreperiod between the "set" and the "go" signals was fixed at 3 s (Fig. 1A) to eliminate the influence of a variable foreperiod on RT. To determine whether participants anticipated the "go" signal, approximately 10% of the trials were catch trials, in which the "go" signal was not delivered.

Data collection. A microphone placed beside the trumpet horn was used to record the onset of the "go" signal. Horizontal force was recorded using a strain gauge (Omegadyne, LCCR-500) placed in series behind the starting blocks. RT was measured as the time between the onsets of the "go" signal and the application of horizontal force to the starting blocks (Fig. 1C). Peak horizontal force was calculated by subtracting the minimum force applied to the blocks between the "set" and "go" signals from the maximum force applied after the "go" signal. Time to peak force was measured as the time between the onset and peak of the horizontal force.

To detect the blink associated with a startle response, EMG activity was recorded from the OOc muscle (Fig. 1B) using a wireless telemetric EMG system (Noraxon Telemyo 2400T XP) sampling at a frequency of 1.5 kHz. The electrode placement was as suggested by Blumenthal et al. (4). A startle response was determined to have occurred in a trial if a blink was recorded ~30–60 ms after the "go" signal as indicated by a burst of EMG activity in the OOc. Although it has been suggested that the sternocleidomastoid is a more reliable indicator of the startle response (7), its activity occurs much later than the OOc and would have been obscured by the large movement artefact associated with the sprint start in the present study. All data were collected on a laptop computer using Noraxon MyoResearch XP (Master version 1.04) and analyzed using a custom written MatLab (The Mathworks, Natick, MA, USA, version r13) program designed to measure RT, peak force, and time to peak force in the manner previously described.

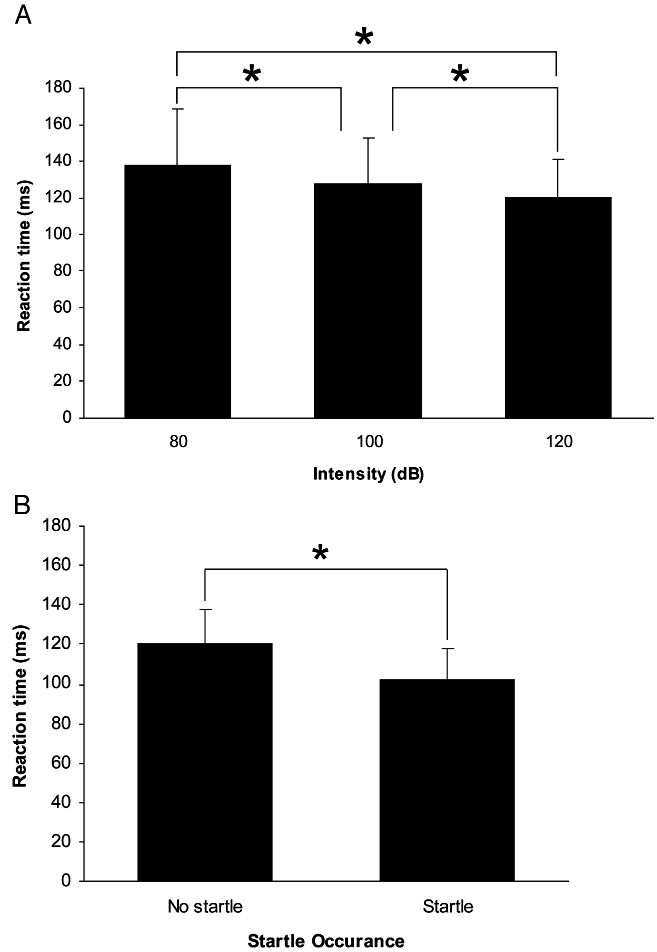

FIGURE 3—The effect of the "go" signal intensity and the startle response on sprint start RT. *A*. The influence signal intensity on RT was tested by randomly varying the loudness of the "go" signal (n = 16 each; *P < 0.01, mixed ANOVA). *B*. The influence of the startle response on RT was tested by considering trials at 120 dB (n = 11 each; *P < 0.02, Student t-test). Data are expressed as mean and standard deviation.

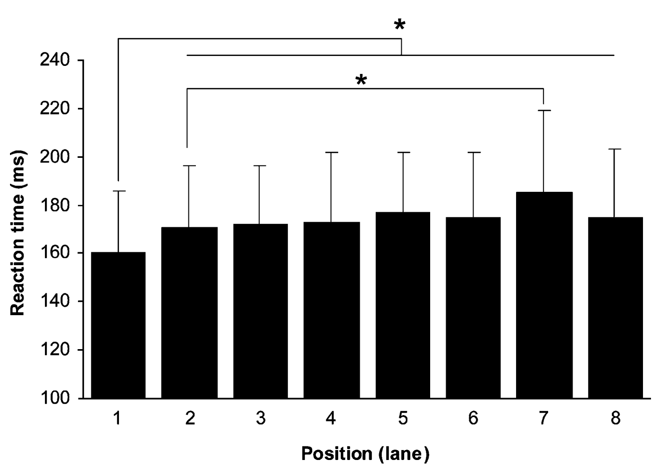

FIGURE 2—2004 Olympic Games RT. RT from the 100-m sprint and 110/100-m hurdles events grouped according to starting position. Data are expressed as mean and standard deviation (*P < 0.01, one-way ANOVA).

Statistical analysis. A two-factor (2 gender by 8 lane) between-subjects ANOVA was used to compare RT from lanes 1 to 8 for data obtained from the 2004 Olympic Games. A mixed ANOVA was used to evaluate the changes in RT, peak force, and time to peak force with training (untrained, trained) and intensity (80, 100, 120 dB) as factors. Paired Student t-tests were used to test for a significant main effect of startle response on RT, peak force, and time to peak force. A one-way repeated-measures ANOVA was used to determine whether there were differences in the frequency of startle responses for the untrained subjects as a function of the three stimulus intensities. A chi square test was used to determine whether the frequency of sub-100 ms RT increased with "go" signal intensity. Newman–Keuls *post hoc* tests were used (where appropriate) when statistically significant main effects of the ANOVA analyses were demonstrated. Statistical analyses were performed using

StatSoft Statistica version 6.1 with an alpha level of $P \leq 0.01$ for the χ^2 test and $P \leq 0.017$ after a Bonferroni correction for *t*-tests and $P \leq 0.05$ for all ANOVA. Descriptive statistics are reported as means and standard deviations.

RESULTS

RT from the 2004 Olympic Games. The analysis revealed main effects for gender ($F(1,359) = 95.81$, $P < 0.0001$) and lane position ($F(7,359) = 3.92$, $P < 0.0004$) and no significant interaction. The gender main effect showed that overall the male sprinters had significantly lower RT (163 ± 22 ms) than the female sprinters (188 ± 28 ms). The Newman–Keuls *post hoc* analysis of the main effect for lane position revealed that the runners in lane 1 had significantly lower RT (160 ± 26 ms) compared to all other lanes (range, 171–185 ms) and that the mean RT for lane 2 (171 ± 25 ms) was significantly lower than lane 7 (185 ± 34 ms; Fig. 2). All other effects were nonsignificant.

Experimental results. With one exception (time to peak, described below), there was no interaction between "go" signal intensity and training on performance in the sprint start. Thus, with that one exception, data from untrained and trained participants were combined for analyses. Increasing the intensity of the "go" signal decreased mean RT ($P < 0.0001$, Fig. 3A). Mean RT at 80 dB (138 ± 30 ms) were significantly higher than at 100 dB (128 ± 25 ms), which were significantly higher than at 120 dB (120 ± 20 ms). In addition, at 120 dB, the occurrence of a startle response further decreased the mean RT by 18 ms ($P < 0.01$; Fig. 3B). Only trials with a 120-dB "go" signal were used to determine the effects of startle because the ANOVA showed for untrained subjects a significant effect of stimulus intensity on frequency of startle responses [$F(2,30) = 4.54$, $P < 0.02$). *Post hoc* analysis revealed a significantly greater number of startles in the 120-dB (23 of 258 trials) condition compared to the 100-dB (8 of 258 trials) and 80-dB (4 of 260 trials) conditions (which were not significantly different from each other).

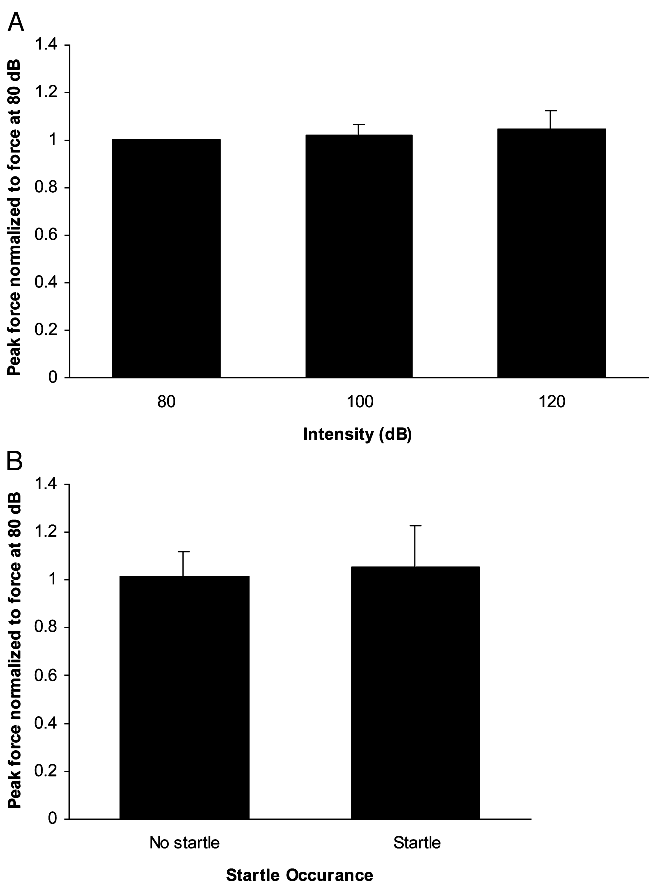

FIGURE 4—The effect of "go" signal intensity and the startle response on sprint start peak force. There were no influences of signal intensity (A, *n* = 16 each; mixed ANOVA) or startle response (B, *n* = 11 each; Student *t*-test) on peak horizontal force. Data are expressed as mean and standard deviation.

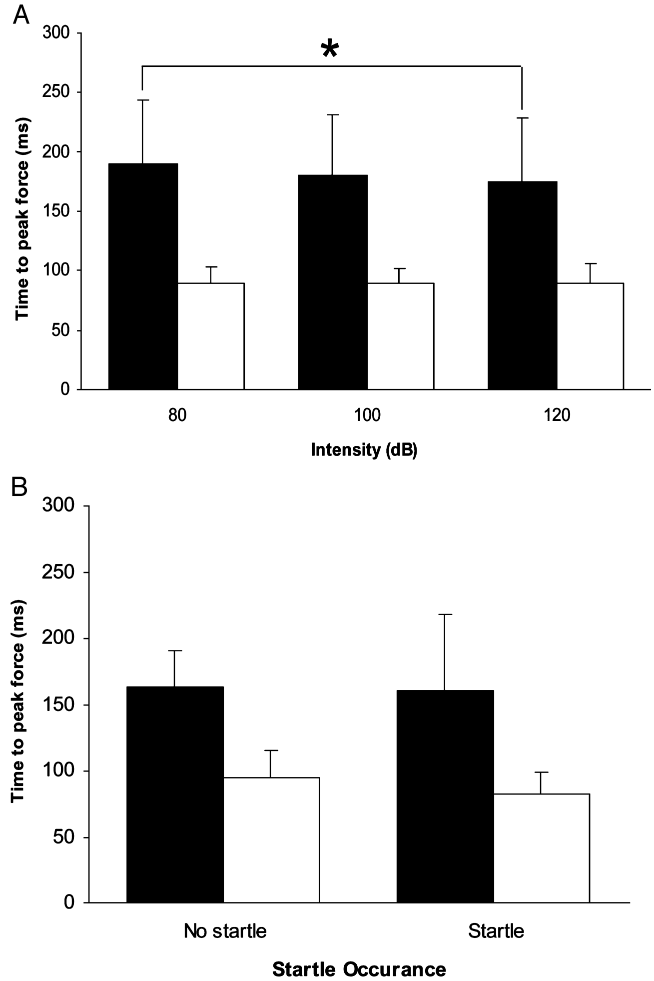

FIGURE 5—The effect of "go" signal intensity and the startle response on sprint start time to peak force. Because of a significant interaction between training and time to peak, participants were grouped as either untrained (*closed*) or trained (*open*). *A*. Signal intensity significantly influenced time to peak force in untrained participants (*n* = 12 each; **P* < 0.03, mixed ANOVA) but had no effect in trained participants (*n* = 4 each; mixed ANOVA). *B*. The startle response had no effect on time to peak force in neither the untrained nor trained participants (*n* = 8 and 3, respectively; Student *t*-test). Data are expressed as mean and standard deviation.

APPLIED SCIENCES

In total, 21% of the RT measured were under 100 ms. The means for the RT that were below 100 ms for each intensity of "go" signal were not significantly different from each other and were 91 ms (range, 72–99), 91 ms (range, 71–99), and 89 ms (range, 75–99) for the 80, 100, and 120 dB "go" signals, respectively. The frequency of sub-100 ms RT increased with "go" signal intensity (43 of 258 trials at 80 dB, 52 of 258 trials at 100 dB, 71 of 260 trials at 120 dB), but this trend was not statistically significant (χ^2 (2) = 5.8, $P > 0.05$). Throughout the study, the "go" signal was anticipated during a catch trial on only one occasion.

Increasing the intensity of the "go" signal did not significantly affect the mean peak horizontal force applied to the blocks ($P > 0.3$; Fig. 4A, data normalized to each individual's mean peak force at 80 dB). However, the time to reach peak force decreased with increasing intensity of the "go" signal in the untrained group ($P < 0.004$; Fig. 5A). Mean time to peak force at 80 dB (190 ± 53 ms) was significantly higher than at 120 dB (175 ± 54 ms). The trained sprinters did not exhibit a change in time to peak force with changes in "go" signal intensity. The occurrence of a startle response had no effect on either peak force ($P > 0.07$; Fig. 4B) or time to peak force ($P > 0.6$; Fig. 5B).

DISCUSSION

Presently, we show that during the 2004 Olympic sprint events in athletics, runners positioned closer to the starter had significantly lower RT than those further away. This effect of lane assignment on RT was particularly strong for runners in lane 1 as their mean RT time was significantly lower than mean RT for runners in all other lanes. The effect of lane assignment was also present but was not as strong for runners assigned to lane 2 whose mean RT was lower than for runners in lane 7. These data prompted our idea that there is an advantage to runners positioned nearer the starter, namely, they hear the "go" signal from the pistol sooner and louder due to sound propagation and the inverse square relationship between sound intensity and distance. We then showed experimentally that increasing the intensity of an auditory "go" signal (i.e., starter's pistol) decreased RT significantly during the sprint start. The louder "go" signal also decreased the time required to reach peak horizontal force applied to the starting blocks for untrained participants, but not trained participants. Interestingly, there was no effect of "go" signal intensity on peak horizontal force. The presence of a startle response decreased RT even further but did not influence the application of force to the starting blocks. These results provide insight into how humans react to auditory stimuli and a physiological rationale for improving the procedures used to start the sprint events at the Olympic Games.

Recently, Carlsen et al. (7) found that increasing the intensity of an auditory "go" signal and inducing a startle response decreased RT for wrist extension in two distinct ways. Graded increases in "go" signal intensity that did not evoke a startle response resulted in graded decreases in RT. This is consistent with the idea that information processing and task execution occur along the typical pathway, but the transmission time along the auditory pathway decreases as the "go" signal intensity increases due to enhanced summation through the cochlea (9), cochlear nucleus (11,16), superior olivary complex (25), lateral lemniscus (1), inferior colliculus (14), medial geniculate body (2), and auditory cortex (5). The net effect is a decrease in response latency that scales with the stimulus intensity (17). Such a mechanism would account for the intensity-graded change in RT observed in our study. This change in processing may also have downstream effects, generating a more synchronous command to relevant motor pools, which could decrease RT and the time required to reach peak force. Presently, we saw a decreased time to peak force only in the untrained participants and suggest that the lack of effect in the trained sprinters may be because they had already optimised their motor program for the start, leaving no room for significant improvement.

In contrast to the graded changes in RT described above, when a startle response occurs, it is thought to alter information processing loops such that the auditory and motor cortices are bypassed and a prepared motor program is released subcortically, perhaps from the reticular formation (6,12,24,28). In this way, portions of the typical audiomotor pathway are bypassed, resulting in a "step-like" decrease in RT. Our present finding that the startle response altered RT, but not parameters of the movement itself (peak force, time to peak force), is consistent with a motor program being released sooner without altering its basic characteristics. This may have clinical applications for disorders such as Parkinson disease in which reduced dopamine levels in the basal ganglia can result in akinesia or "freezing" of movement initiation. Startle responses in Parkinson patients are of similar amplitude and habituate less compared to healthy age-matched populations (27,31). The use of rhythmic auditory cues during locomotion for Parkinson patients can improve many aspects of locomotor performance (21,26), but thus far auditory cues to improve gait initiation have proven unsuccessful (10,21). Triggering a startle response may represent a novel means of initiating movement whereby regions of impaired cortical processing are bypassed and motor programs are released subcortically.

We suggest that at the 2004 Olympic Games runners positioned closer to the starter reacted significantly earlier than the other runners because they heard a louder "go" signal sooner. This effect of sound intensity on RT would be especially pronounced if the "go" signal intensity was such that a startle response was induced in runners closest to the starter but not those farther away. The difference we found in mean RT for runners in lane 1 compared to all other lanes (range, 11–25 ms) is not trivial, given the fact that first and second places in the men's 100-m sprint final in 2004 were separated by only 10 ms. Our results may in fact underestimate the effect of a loud starter's pistol at the Olympic Games. Although we had ethical approval to use a "go" signal of up to 120 dB, in reality, a starter's pistol can be as loud as 181 dB (23). Regardless of the observed relationship between auditory intensity and RT, final race position is rarely correlated with RT and runners in lane 1 do not win more championships (20). This may be due to the fact that although runners are randomly assigned to a lane during the heats, in subsequent races, they are assigned lanes based on previous performance with the fastest runners positioned in the middle lanes. However, to remove undue bias and ensure that runners in all lanes hear the pistol at the same time and intensity, we recommend that Olympic sprint competitions use a silent pistol to deliver the "go" signal as is currently done at the IAAF World Championships.

Although the present study was not specifically designed to address the 100-ms false start threshold used at most sprint competitions, we observed many RT (21%) under this threshold, similar to the recent results of Pain and Hibbs (22). In our study, only once did a participant start during a catch trial; thus, these low RT do not reflect an anticipation of the "go" signal. Importantly, in both our study and that of Pain and Hibbs (22), RT was calculated as the time to onset of horizontal force applied to the starting blocks; in contrast, the IAAF false start detection protocol uses the time required to reach a criterion threshold of force applied (22). However, our data show that humans can react during a sprint start well before 100 ms, and we estimate that many of our trials would have been considered false starts according to the criteria used by the IAAF. Therefore, we strongly believe that this threshold value requires a more thorough investigation to confirm its validity.

In summary, "go" signal intensity and the startle response significantly influenced RT performance during a sprint start. These two parameters had distinct effects (only intensity affected time to peak force) and were likely mediated by separate mechanisms. These experiments demonstrate that the relationship between sound intensity and performance in a RT task, which has been previously shown using more simple movements, holds true in the more complex, real-world situation of initiation of locomotion for the sprint start. This study provides the first experimental evidence to suggest that current procedures used at the Olympic Games should be changed because runners closest to the starter have the advantage of hearing the loudest "go" signal; consequently, they react sooner than their competitors.

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REFERENCES

1. Aitkin LM, Anderson DJ, Brugge JF. Tonotopic organization and discharge characteristics of single neurons in nuclei of the lateral lemniscus of the cat. *J Neurophysiol*. 1970;33(3):421–40.
2. Aitkin LM, Dunlop CW. Interplay of excitation and inhibition in the cat medial geniculate body. *J Neurophysiol*. 1968;31(1): 44–61.
3. Angel A. Input–output relations in simple reaction time experiments. *Q J Exp Psychol*. 1973;25(2):193–200.
4. Blumenthal TD, Cuthbert BN, Filion DL, Hackley S, Lipp OV, van Boxtel A. Committee report: guidelines for human startle eyeblink electromyographic studies. *Psychophysiology*. 2005; 42(1):1–15.
5. Brugge JF, Dubrovsky NA, Aitkin LM, Anderson DJ. Sensitivity of single neurons in auditory cortex of cat to binaural tonal stimulation: effects of varying interaural time and intensity. *J Neurophysiol*. 1969;32(6):1005–24.
6. Carlsen AN, Chua R, Inglis JT, Sanderson DJ, Franks IM. Can prepared responses be stored subcortically? *Exp Brain Res*. 2004; 159(3):301–9.
7. Carlsen AN, Dakin CJ, Chua R, Franks IM. Startle produces early response latencies that are distinct from stimulus intensity effects. *Exp Brain Res*. 2006;176(2):199–205.
8. Carlsen AN, Hunt MA, Inglis JT, Sanderson DJ, Chua R. Altered triggering of a prepared movement by a startling stimulus. *J Neurophysiol*. 2003;89(4):1857–63.
9. Deatherage BH, Eldredge DH, Davis H. Latency of action potentials in the cochlea of the guinea pig. *J Acoust Soc Am*. 1959;31:479–86.
10. Dibble LE, Nicholson DE, Shultz B, MacWilliams BA, Marcus RL, Moncur C. Sensory cueing effects on maximal speed gait initiation in persons with Parkinson's disease and healthy elders. *Gait Posture*. 2004;19(3):215–25.
11. Goldberg JM, Brownell WE. Discharge characteristics of neurons in anteroventral and dorsal cochlear nuclei of cat. *Brain Res*. 12-21-1973;64:35–54.
12. Grillner S, Hellgren J, Menard A, Saitoh K, Wikstrom MA. Mechanisms for selection of basic motor programs—roles for the striatum and pallidum. *Trends Neurosci*. 2005;28(7):364–70.
13. Ikai M, Steinhaus AH. Some factors modifying the expression of human strength. *J Appl Physiol*. 1961;16:157–63.
14. Irvine DR, Gago G. Binaural interaction in high-frequency neurons in inferior colliculus of the cat: effects of variations in sound pressure level on sensitivity to interaural intensity differences. *J Neurophysiol*. 1990;63(3):570–91.
15. Jaskowski P, Rybarczyk K, Jaroszyk F, Lemanski D. The effect of stimulus intensity on force output in simple reaction time task in humans. *Acta Neurobiol Exp (Wars)*. 1995;55(1):57–64.
16. Kitzes LM, Gibson MM, Rose JE, Hind JE. Initial discharge latency and threshold considerations for some neurons in cochlear nuclear complex of the cat. *J Neurophysiol*. 1978;41(5): 1165–82.
17. Klug A, Khan A, Burger RM, et al. Latency as a function of intensity in auditory neurons: influences of central processing. *Hear Res*. 2000;148(1–2):107–23.
18. Kohfeld DL, Santee JL, Wallace ND. Loudness and reaction time: I. *Percept Psychophys*. 1981;29(6):535–49.

19. Lennart Julin A, Dapena J. Sprinters at the 1996 Olympic Games in Atlanta did not hear the starter's gun through the loudspeakers on the starting blocks. *New Stud Athl*. 2003; 18(1):23–7.
20. Mero A, Komi PV, Gregor RJ. Biomechanics of sprint running. *Rev Sports Med*. 1992;13(6):376–92.
21. Nieuwboer A, Kwakkel G, Rochester L, et al. Cueing training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial. *J Neurol Neurosurg Psychiatry*. 2007;78(2): 134–40.
22. Pain MT, Hibbs A. Sprint starts and the minimum auditory reaction time. *J Sports Sci*. 1-1-2007;25(1):79–86.
23. Rothschild MA, Dieker L, Prante H, Maschke C. Peak sound pressure levels of gunshots from starter's pistols (German). *HNO*. 1998;46(12):986–92.
24. Rothwell JC. The startle reflex, voluntary movement, and the reticulospinal tract. *Suppl Clin Neurophysiol*. 2006;58:223–31.
25. Sanes DH, Rubel EW. The ontogeny of inhibition and excitation in the gerbil lateral superior olive. *J Neurosci*. 1988;8(2): 682–700.
26. Thaut MH, McIntosh GC, Rice RR, Miller RA, Rathbun J, Brault JM. Rhythmic auditory stimulation in gait training for Parkinson's disease patients. *Mov Disord*. 1996;11(2):193–200.
27. Valldeoriola F, Valls-Sole J, Tolosa E, Ventura PJ, Nobbe FA, Marti MJ. Effects of a startling acoustic stimulus on reaction time in different parkinsonian syndromes. *Neurology*. 1998;51(5): 1315–20.
28. Valls-Sole J. Contribution of subcortical motor pathways to the execution of ballistic movements. *Suppl Clin Neurophysiol*. 2004;57:554–62.
29. Valls-Sole J, Rothwell JC, Goulart F, Cossu G, Munoz E. Patterned ballistic movements triggered by a startle in healthy humans. *The Journal of Physiology Online*. 1999;516(Pt 3):931–8.
30. Valls-Sole J, Sole A, Valldeoriola F, Munoz E, Gonzalez LE, Tolosa ES. Reaction time and acoustic startle in normal human subjects. *Neuroscience Letters*. 1995;195(2):97–100.
31. Vidailhet M, Rothwell JC, Thompson PD, Lees AJ, Marsden CD. The auditory startle response in the Steele–Richardson–Olszewski syndrome and Parkinson's disease. *Brain*. 1992;115(Pt 4): 1181–92.