In search of the 70 kph human: challenging the limits of human muscle contraction time – a pilot investigation

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Interest in sprint running has been fueled by the remarkable performance in 100-and 200-metre events at the 2008 Olympic Games. Amid this interest, speculation mounts as to how fast humans can run and to the existence of new types of fast-twitch fibers as the mechanism that realizes faster performances. This paper adopts the view that humans are limited in how fast they can run by how much force they can apply within the muscle contraction times inherent of fast running and proposes a method by which adaptation may be forthcoming to strengthen the locomotive muscles in humans within that required contraction time or shorter contraction times. The proposed method consists of the fast foot drill exercise executed with the intent of increasing the rate of stepping; training with this method was carried out over 16 weeks. The analysis of the post-training stepping rate shows that movement frequencies in human locomotive muscle approaches 7 muscle contractions per second. The analysis also shows that muscle activation times approach 90 milliseconds for the vastus lateralis muscle and 55 milliseconds for the biceps femoris muscle. Furthermore it is speculated that as a result of this training method muscle contraction times may approach and surpass the time limits for humans that are currently accepted in science. The hypothesis is that by combining the fast foot drill with progressive external resistance, runners can increase their force production within the ground contact time inherent of fast running that currently limits how fast humans can run.

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With the remarkable performances of Usain Bolt in the 100-m sprint, people are speculating about the capacity of humans to run faster. Interest from the population at large with regards to these incredible performances have led some scientist's to propose, through media, that they are attributable to the existence of the super fast-twitch fiber in fast humans (1); which in the absence of published scientific data remains unproven. According to other scientists the faster runners produce more vertical force instead of repositioning their legs faster (2) but humans can already produce 30% more average and 16% more peak vertical force when hopping than they currently choose to use in a maximal sprint which should mean that humans are capable of running much faster already; between 50- and 70 kph (3). Science is now debating whether human sprint performance is instead limited by the capacity to produce force in the smaller and smaller ground contact times as speed increases; as faster muscle fibers would permit the limbs to apply greater forces (3). Without any scientific proof to date of super fast-twitch fiber with distinct properties in humans, maybe the fastest sprinters simply have fast-twitch fiber that has adapted to contract slightly faster through specific training.

In the animal kingdom, super fast muscle powers high-frequency sound production and visual tracking which requires low forces (4) but in human sprinters, if the super fast fiber does exist, large amounts of force would have to be generated by the locomotive muscles. The super fast-twitch fiber which is used for sound production in the toadfish (5), produces only one quarter as much force per unit area as locomotive muscle fibers at a much greater rate of energy consumption; in effect trading energy and force for speed (4). This high rate of energy consumption suggests that the super fast-twitch fiber is not what propels today's fastest humans who demonstrate excellent performances over longer sprint distances of 200– and 400– m. Equally the low force output of the super fast-twitch fiber make it unlikely as a mechanism that will propel humans towards 70 kph.

Data at speeds of 9.59 and 9.96 m/s show that sprinters produce around 338 and 312 N of horizontal force respectively (9, 10); there is an absence of horizontal force data from higher speeds of running especially from the fastest humans although the trend suggests that horizontal force per unit of bodyweight increases with velocity (6).

Motion is governed by Newton's law of physics as it relates to impulse. This states that impulse (force multiplied by time) is equal to the change in momentum (mass multiplied by the difference between final velocity and initial velocity); **Ft = m(v-u)** where **F** is force, **t** is time, **m** is mass of the body, **v** is final velocity and **u** is initial velocity. The implication is that for a sprinter to increase their velocity during a step, they must produce force in the time in which the foot is in contact with the ground; an increase in either force or time will therefore increase velocity. The data trend from studies on running up to 10 m/s shows that contact time and impulse diminishes with velocity whilst horizontal force increases (6).

Researchers say that forward movement can only be achieved with horizontal propulsion (7,8). Data at speeds of 9.59 and 9.96 m/s show that sprinters produce around 338 and 312 N of horizontal force respectively (9, 10); there is an absence of horizontal force data from higher speeds of running especially from the fastest humans although the trend suggests that horizontal force per unit of bodyweight increases with velocity (6). However given that movement of the legs are the functional result of activating muscles (11) and knowing that even athletes with a preponderance of fast-twitch fiber produce less force at faster velocities of contraction (12), humans may struggle to produce enough horizontal force to reach 70 kph as air resistance increases and as ground contact time shortens even more.

Forces must also be produced to overcome the effects of gravity. It has been shown that vertical forces of 2.14 times bodyweight are produced at speeds of 9.92 m/s (2) whilst other researchers report net vertical propulsive forces of 615 N at 9.59 m/s (9) and of 797 N at 9.96 m/s (10). We cannot ascertain the net vertical forces at speeds greater than these although when horizontal force is aided with the sprinter being pulled by external force horizontally, during supra-maximal towing speeds of 10.82 m/s net vertical force was reported at 621 N (10). Faster running speeds are said to be governed by vertical force production (2, 13) but sprinters choose not to produce as much vertical force when sprinting as when hopping (3,9) and as speed gets faster and faster vertical forces generated may not necessarily be increasing (6). Maybe it is not desirable to produce too much vertical force at the highest speeds; as smaller vertical velocities, which would result from smaller vertical forces, were recorded in faster Olympic finalist 200–m sprinters (14). If the sprinter increases vertical forces they would produce greater vertical displacement resulting in longer stride lengths and less steps overall but would the horizontal velocity necessarily facilitate faster run times? In contrast, according to Bolt's coach, shortening stride length was one reason attributed to his success (15). Science is now debating that maximum forward speed is set up by minimizing time in the air between steps; the shorter aerial phase resulting from lower vertical forces and shorter ground contact times (3).

The limiting factor faced by the aspiring 70 kph human may be the time in which the foot of the runner is in contact time with the ground; a study of forward and backward running suggests that it is contact time that is keeping them from going faster in any direction (3). Humans are unable to prolong their ground contact time when running at top speed, unlike some mammals that can gallop with pronounced back bone bending, but instead must apply greater mass-specific forces during shorter periods of foot-ground contact (3). This contact time has been measured to be 94 milliseconds (ms) at a maximal running velocity of around 10–11 m/s (10,16). At higher speeds of 11.76 m/s for world class sprinters contact with the ground was observed for 80-83 ms (17). The latter times are within the range to reach peak tension of 81 ms in quadriceps muscles of the human leg and so we may be limited by muscle contraction time as to how much force we can produce against the ground (3,18). However human fast fibers have been measured with single twitches of 55-88 ms (19). Perhaps what is currently limiting human running speed is that we have yet to design a training modality that substantially increases our ability to produce force in these small muscle contraction time constraints or one that shortens muscle contraction time as well.

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A logical explanation for sprinters having greater type II than type I fiber areas in their leg extensor muscles, and therefore being faster, is that their training consists of fast repetitive movements (10). Researchers have found that a greater percentage of fast-twitch fiber in the legs correlates with faster sprint performance (20,21). Sprint running involves stride rates of 4–5 steps per second (10) or 2–2.5 steps per second (and implied muscle contraction rates) for each leg. Quicker activation times may have been present in sprint cycling of up to 200 rpm or approximately 3.33 contractions per second per leg but no change was found in minimum muscle contractile times from training at that rate (18). Perhaps we could influence minimum contraction times with even quicker frequencies of movement. One sprint training exercise that may provide an avenue to achieving this is the fast foot drill consisting of fast repetitive movements of stepping usually over a confined distance (22). Such an exercise practiced by track athletes over 12 months has improved fast foot drill stepping rates per leg from 4.5 to 6 steps per second (personal correspondence). The hypothesis herein is that the fast foot drill may produce shorter muscle contraction times; it is not intended to imply an increase in stride rate. Furthermore, these short muscle contraction times must be supplemented with strength training during the exercise to increase force production within these small time constraints; through biological adaptation. To my knowledge no study has observed the rate of stepping or the time of muscle activation in such an exercise.

The signal associated with the activation of a muscle is called an electromyogram or EMG (23) an analysis of which will reveal the rate of stepping and the time of muscle activation. A technique used to analyze EMG called a linear envelope is indicative of muscle contraction as a linear envelope said to closely match muscle tension (24) which under dynamic contraction conditions is seen to lag behind the EMG signal (23). In normal sprinting total activation times have been measured to be less than 145 ms in the vastus lateralis (VL) at maximal speed during the ground contact time of approximately 110 ms (11, 25). However world class sprinters have ground contact times of approximately 80 ms which could imply shorter muscle activation times than the 145 ms mentioned above. With such a difference between muscle activation time and ground contact time and as this paper alludes to possible adaptations within the neuromuscular system, the analysis will focus on EMG recording from the muscle itself.

Method

The available resources limited this study to one investigative bout, for which only one post-training protocol analysis was taken. The author is the subject in this study; male aged 37 years, 172 cm in height and weighing 79 kg. The electromyography (EMG) observation was conducted when warming up and testing the equipment whilst participating in a separate study. The author was familiar with the procedures and risks of the EMG analysis. For the analysis the author performed the fast foot drill consisting of rapid alternating steps whilst moving forwards over approximately 2 meters, with an external load resistance of 20 kg equivalent to at least 971 N of force including body weight when standing. The fast foot drill has been practiced regularly by the author under the guidance of a qualified sprint coach.

Training program

The training program was conducted over 16 weeks with training once per week consisting of 3 sets of 30–50 quick steps. The time to complete the steps is taken (with a stopwatch) for each set with a two minute rest period between each set; the goal being to complete the steps in as short a time as possible. In addition, for each set the subject must carry an external load which is held in each hand. Taking into account that the super fast-twitch fiber sacrifices force for speed of contraction in animals (4), any adaptation to muscle contractile properties in human locomotive muscle from an exercise like the fast foot drill should not sacrifice force production. With this in mind the force magnitude was at least maintained during the training protocol through the addition of an external load. This load is varied throughout the training program (see Appendix) using a common protocol of progressive overload with cycled lower intensity periods (26). The choice of executing 30 steps is based on the onset of fatigue. As adaptation to fatigue occurred over time, this step number increased to 40 and then to 50

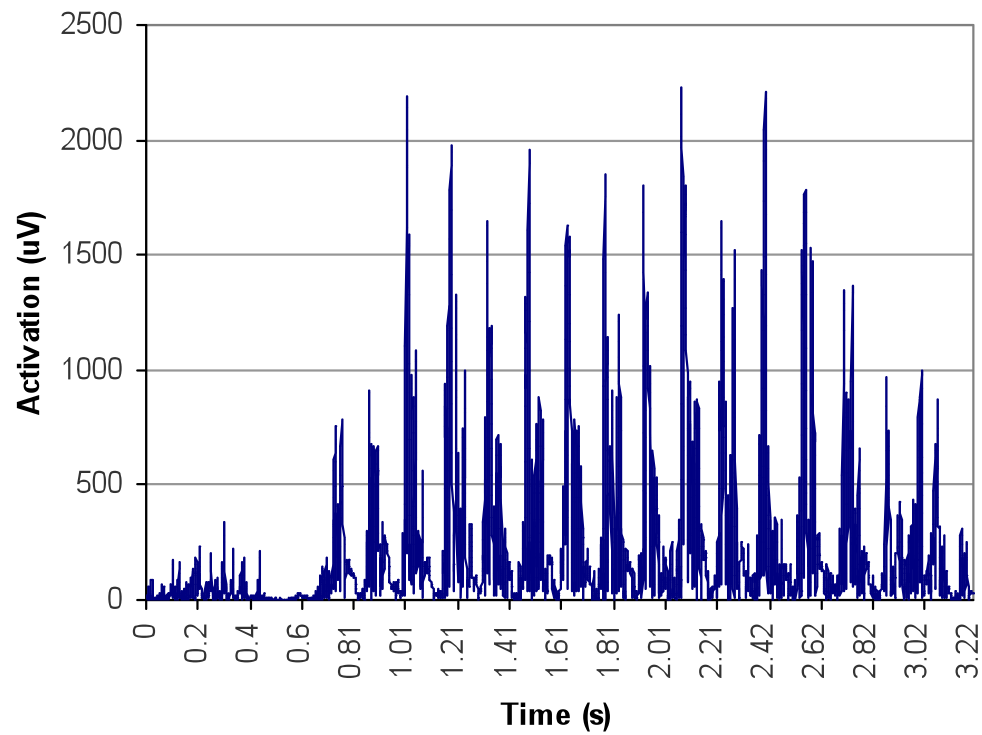

Figure 1 | Raw rectified EMG data of the VL. The fast foot drill starts at approximately 0.7 seconds. A hop (at time 0-0.45 s) initiates the fast foot drill and is executed shortly after the EMG recording commences.

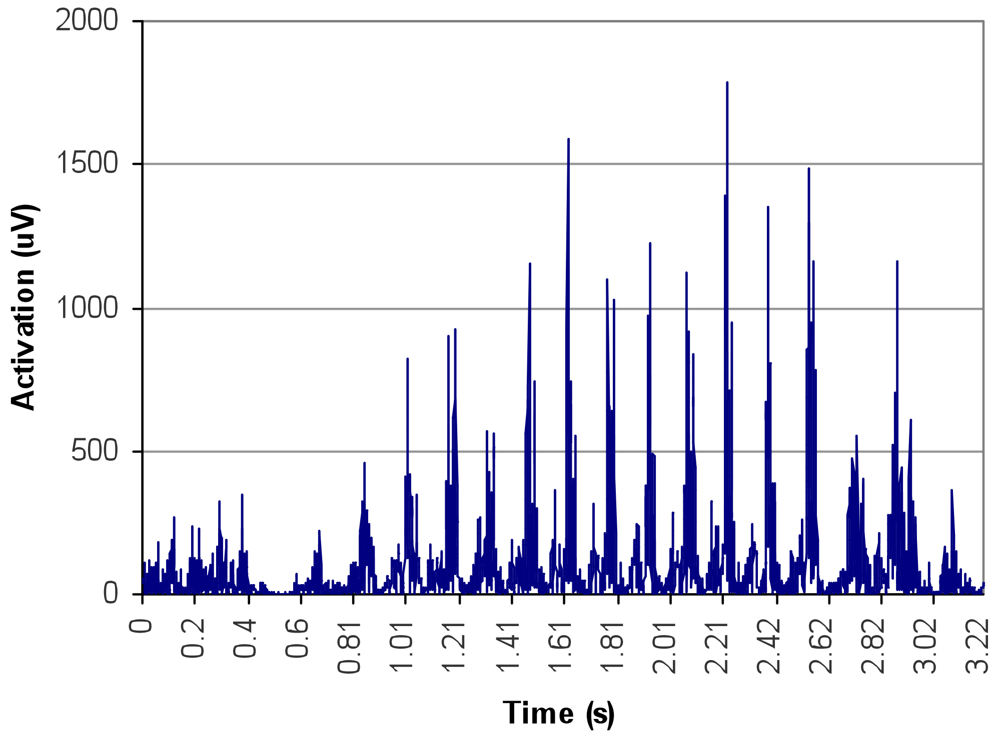

Figure 2 | EMG data of the biceps femoris in the fast foot drill. Responses start at approximately 0.7 seconds after a hop (at time 0-0.45 s).

in each cycle. As opposed to increasing the load throughout the program, the decision was made to increase the number of repetitions so that practice could take place with a larger number of repetitions which should facilitate skill acquisition of the task (27).

Data processing

Surface EMG recordings were collected using Noraxon MyoResearch (Noraxon U.S.A. Inc.) telemetric EMG system. Signals were sampled at 1500 Hz. EMG skin preparation procedures of shaving, abrasion and cleaning were completed. Bipolar electrodes were placed over the muscle belly of the vastus lateralis (VL) and the biceps femoris (BF) of the right leg with a reference electrode placed at the ankle. Data was analyzed using an Excel spreadsheet (Microsoft Office Professional Edition 2003). As this paper is a pilot observation, the raw data is presented. Additionally, one step is isolated for individual observation and a linear envelope is superimposed on the raw data; filtering for frequencies of less than 20 Hz that may arise especially from firing of motor units (28) to provide an indication of the muscle tension (24).

Results

The EMG measurements displayed of the VL and BF show the rate of steps (fig. 1 & 2) to be approximately 7 steps per second. Also the muscle activation time could be less than 90 ms for the VL and as low as 55 ms for the BF (fig. 3 & 4) as seen from the linear envelope; a moving average. In addition, the activation level is much greater during the fast foot drill (time 0.6 seconds onwards) than the activation level observed for the hop (time 0-0.45 seconds approximately) that initiates the fast foot drill (fig. 1 & 2). It can be seen that peak activation levels for the fast foot drill is approximately 5.5 times greater than that reached for the hop in both the VL and BF conditions.

Discussion

The fast rate of activation in this experiment is the result of training with the fast foot drill exercise. After approximately 16 weeks of deliberate practice to increase the rate of stepping during training, the author had increased the step rate from 4 to 7.5 per second for each leg. It could not be ascertained whether this improvement to stepping rate was facilitated by reduced vertical elevation of the foot with each step or through reduced ground contact time. Also the deliberate practice included a progression in adding external resistance which may have aided in reducing vertical elevation. In the absence of studies on movement speed of human legs, a study of movement speed of hands showed the world's fastest drummer to have a tapping rate of 10 Hz with each hand; a rate gained from deliberate practice to improve tapping rate (29). In comparison, ordinary drummers and non-drummers had mean tapping rates of 6.6 Hz. From the study of drummers and with regards to the worlds fastest drummer it could be inferred that deliberate practice to execute the fast foot drill faster in human locomotive muscles may lead to faster step rates and shorter muscle activation times than recorded here. In order to have any relevance to athletic sport any future research in this area needs to quantify the level of muscle recruitment as a percentage of maximum voluntary contraction and rate of force production.

Research is now enlightening us to the limit of running speed as being the maximum rates, as opposed to maximum forces, at which the limbs can apply the forces required (3). Within the current foot-contact time exhibited in modern sprinters, it is estimated that only 46% of maximum available force from the quadriceps can be applied to the ground (3). Studies show that greater force can be

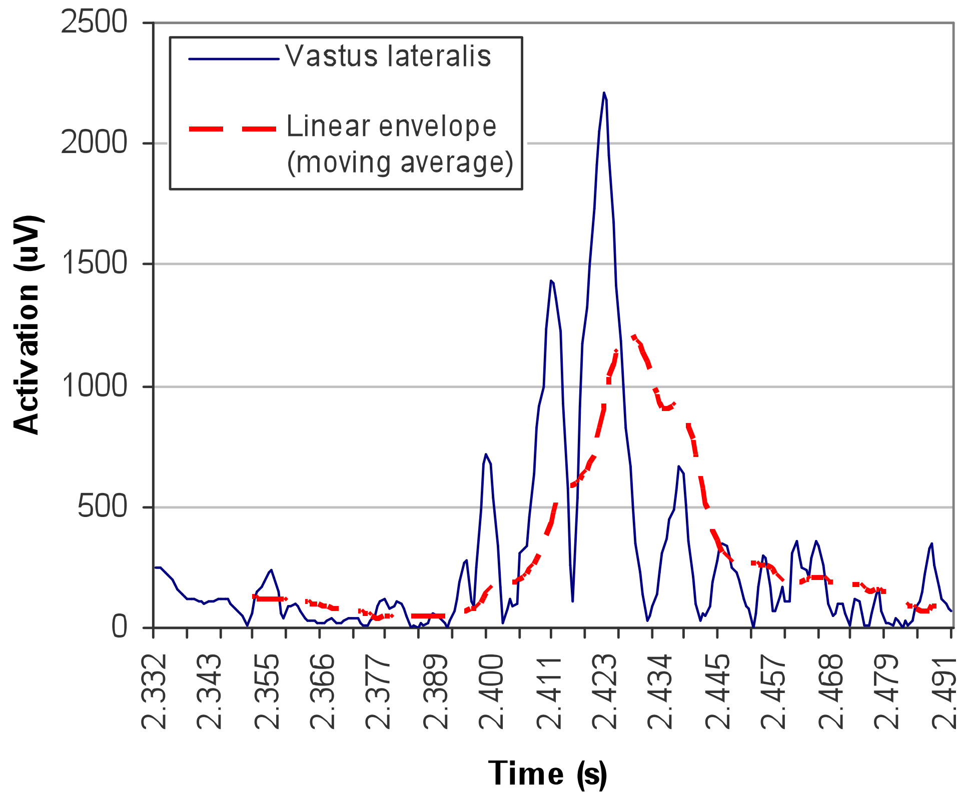

Figure 3 | Superimposition of EMG vastus lateralis (VL) data and linear envelope. Date presented are the moving averages over 30 consecutive EMG measurements (signals less than 20 Hz filtered).

applied within shorter time frames as a result of training with explosive type exercise with its short force production times and high contraction velocities compared to training with the longer force production times typical of heavy strength training exercise (30,31). For example, after 24 weeks of training the time to generate 1000 N improved by 20 % from 52– to 41.4 ms and the time to generate 2000 N improved by 23% from 129.7– to 99.4 ms respectively from explosive strength training (31). In contrast there was no improvement measured from heavy strength training in generating 1000 N from 45.4– to 46.2 ms though there was an improvement of 7% in generating 2000 N from 116– to 107.5 ms (30). Explosive exercise is typically carried out with minimum contact times of 120 ms for bounding and around 190 ms for hopping (9); it is hypothesized here that strength training exer-

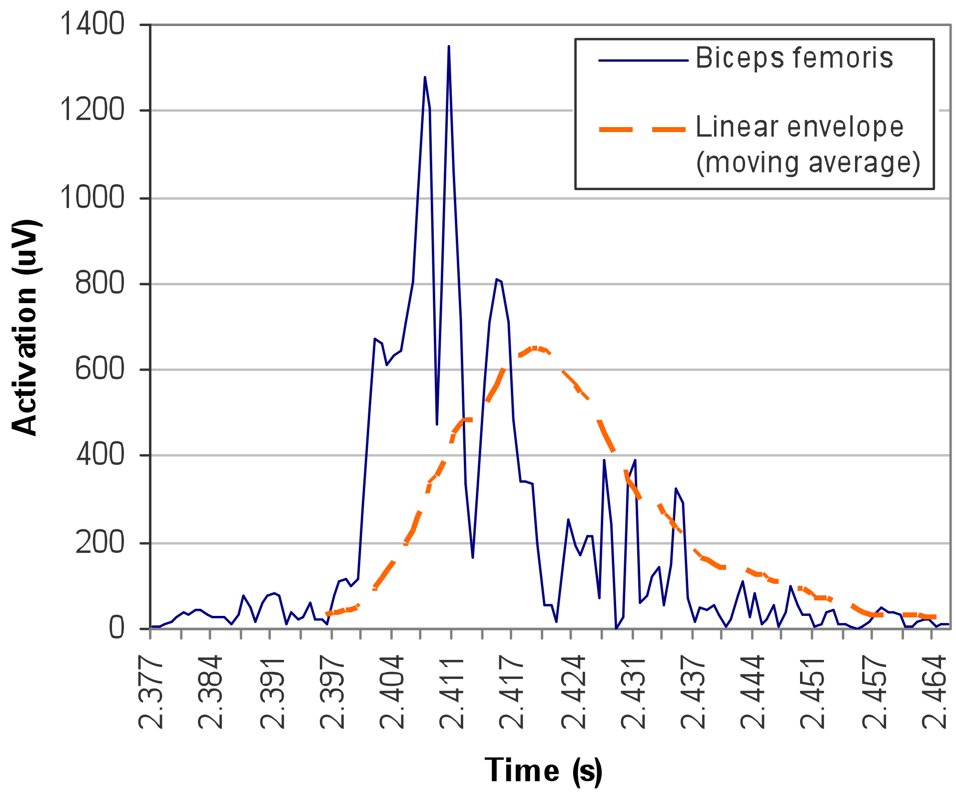

Figure 4 | Superimposition of EMG biceps femoris (BF) data and linear envelope. Date presented are the moving averages over 30 consecutive EMG measurements (signals less than 20 Hz filtered).

cise carried out in the shorter activation times of less than 100 ms demonstrated in the fast foot drill will have a greater impact on the rate of force development than that produced by explosive strength training. This would allow a greater percentage of maximum available force to be produced by the limbs against the ground within the time constraints inherent of fast running of 94-80 ms (10,16,17) as mentioned previously. Future research needs to determine the change in rate of force development over the course of such a training protocol or a similar protocol.

The data presented here suggests that muscle activation times of 90 ms are possible in the VL and 55 ms in the BF which could infer a reduction in muscle contraction time. It is assumed that these times will reduce as the rate of stepping increases from 4 to 7.5 per second through a training regime as mentioned previously. As running speeds get faster foot-contact times will get progressively shorter (3). Under these circumstances the fast foot drill provides an avenue for specific rate of force production practice. If the fast foot drill can be performed at higher frequencies than demonstrated here the notion of reducing muscle contraction times or even fiber single twitch times to or beyond the current limits of human ability is an interesting question. This could ultimately lead to running speeds once thought of as only a dream (3) provided the magnitude of force generated by the muscles in the exercise introduced here is relevant for sprinting at those speeds.

From the studies mentioned previously the magnitude of force needs to be around 600–700 N of net vertical force and around 300 N of horizontal force within contact times of less than 90 ms; a resultant force of approximately 1450 N for a 75 kg person. One cannot ascertain how much force is required to reach speeds much faster than that currently recorded as the fastest; however if the impulse can be increased whilst contact time reduces then it is probable that speeds will improve further. The force used in this observation was at least 971 N; any vertical displacement of the centre-of-mass (CM) would equate to force greater than this according to the equation **F = mg + ma** where m is mass of the body and **a** is the acceleration of the CM vertically upward (32). For example, a vertical displacement of 1 cm with 20 kg by the subject herein occurring from a vertical velocity produced within 100 ms would equate to a force magnitude of approximately 1400 N; **a = √(2gS) / t** where **S** is vertical displacement, **g** is gravity and **t** is time of force production (from classical mechanics equations: **v2 = u2 + 2gS**, **a=(v-u)/t)**. Any future study should measure the forces and force-time characteristics of the fast foot drill using a force platform.

Whether the fast foot drill or any adaptations forthcoming thereof has any efficacy to sprinting speed remains an open question. Likely there is no noticeable benefit given that many sprinters and sports participants practice the fast foot drill regularly and approach muscle activation times observed in this pilot investigation. One could ascertain that the fast foot drill in its current form is not specific enough to the movement in actual top speed sprinting to produce any significant transfer of strength gains; if there is any attempt to gain strength in its generally practiced form (33,34). Additionally, the recruitment pattern of the muscles is important as improvements in strength must be initiated in the muscles that generate the forces with the same pattern observed during sprint running; only through training with the same pattern and speed will the coordination of agonist and synergist muscles improve effectively (35,36,37). It would be of interest whether the fast foot drill performed with more biomechanical specificity to maximal sprinting would have any effect on sprinting speeds.

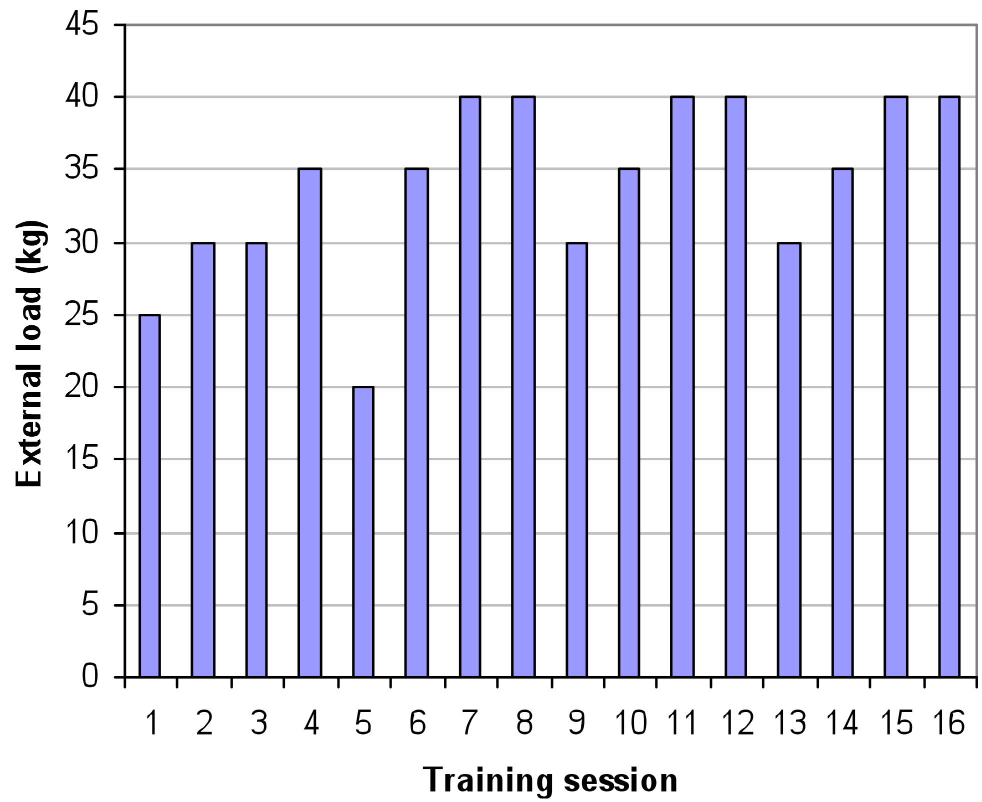

Figure 5 | External load following 16 weeks of the training program.

This study was limited without the aid of analysis from a force platform which otherwise could have compared the timing of force production to the time of muscle activation in the single experimental observation. In addition a force platform may have revealed information on the rate of force development although this would benefit more from observation over the span of a training protocol. Ultimately such an observation needs to be examined in the context of sprinting movements to have any relevance to running at faster speeds. The hypothesis of reducing muscle contraction time needs more in-depth and rigorous evaluation.

Conclusion

The short muscle activation times seen from this pilot study are a result of deliberate practice to reduce such and challenge the limits of human fast-twitch fiber contraction times in human locomotive muscles. If this can be replicated by other humans the fast foot drill may be a mechanism that could transform properties of some human locomotive fast-twitch fiber and promote shorter activation. In this regard the fast foot drill may facilitate the capacity of humans to produce force in shorter ground contact times that are currently limiting human running speed provided that biomechanical and neuromuscular specificity is observed in training. Perhaps the real benefit of a training method with short muscle activation times and likely short ground force production times is in its contribution to rate of force development. However it is important to note that this paper represents a pilot investigation only of the rate and time of muscle activation. Nevertheless, the information presented in this paper alludes us to the possibility of human running speeds beyond the current 44 kph of Usain Bolt and some way towards the 70 kph human. H

About the Author

Jeremy Richmond is an Exercise Physiologist in Rehabilitation. His research interests include fast-twitch fiber recruitment and development, sprinting biomechanics/training methods, genetic advantage in sprinting, exercise for weight loss, and back pain rehabilitation.

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