EXPLOSIVE PLANTAR FLEXOR PERFORMANCE: A COMPARISON OF ELITE SPRINTERS VERSUS PHYSICALLY ACTIVE INDIVIDUALS

Evan D. Crotty[1], Laura-Anne M. Furlong[2], and Andrew J. Harrison[1]

Biomechanics Research Unit, University of Limerick, Limerick, Ireland[1]
School of Sport, Exercise and Health Sciences, Loughborough University, UK[2]

This study examined differences in explosive muscular torque production of the plantar flexors of participants with differing training backgrounds. Explosive performance of a group of elite sprinters (*n* = 14) and physically active individuals (*n* = 14) were examined during explosive and maximal isometric contractions across different muscle-tendon unit (MTU) lengths. The rate of torque development (RTD) across time windows (0-50, 50-100, 100-150 ms) and maximal voluntary torque (MVT) was measured. Sprinters exhibited greater early phase RTD (0-50, 50-100 ms) across MTU lengths. Relative MVT was greater for sprinters at the dorsiflexed MTU length only. The results suggest sprint-specific training contributes to the improved explosive performance of the plantar flexors across MTU lengths, particularly in the early phase of muscular contraction.

KEYWORDS: track and field, ankle joint, rate of force development, maximal voluntary torque

INTRODUCTION: Explosive muscular force production is important for performance across a range of sports movements, particularly when the time to develop force is <200 ms. Sprinting is an explosive activity that requires coordinated muscle activation and a large amount of torque generation in a limited time frame. Elite sprinters regularly engage in explosive-type training, with evidence indicating increases in motor unit discharge rate from this training type (Van Cutsem, Duchateau, & Hainaut, 1998). Rate of force development (RFD) is mainly determined by the capacity to maximally activate the muscle in the early phase (50-75 ms) of a contraction, resulting mainly from an increase in the discharge rate of motor units (Maffiuletti et al., 2016). RFD is commonly evaluated to characterise the explosive strength of athletes. Explosive athletes such as sprinters would be expected to have a greater joint torque-producing ability, with research showing increased RFD in the knee extensors of power athletes versus controls (Tillin, Jiminez-Reyes, Pain, & Folland, 2010). The plantar flexors are an important muscle group in energy generation for acceleration (Charalambous, Irwin, Bezodis, & Kerwin, 2012). However, maximal RFD of the plantar flexors has been shown not to differ between power and endurance athletes (Kyröläinen & Komi, 1994). Many studies examine explosive muscular performance at a single joint-angle configuration. However, muscle-tendon unit (MTU) length changes can influence the maximum force a muscle can produce. An examination of the force-producing capabilities across MTU lengths is important to attain a broader understanding of the mechanisms underpinning explosive plantar flexor performance. Previously unexamined, this study compares the explosive torque producing capabilities across MTU lengths of sprinters and physically active individuals, examining the RFD force-time curve, and maximally voluntary torque (MVT), which is associated with late-phase RFD (Folland, Buckthorpe, & Hannah, 2014). Examining these participant groups may uncover any training-induced adaptations in explosive force production.

METHODS: Following approval by the local University Research Ethics committee, twenty-eight participants (14 ♂, 14 ♀) volunteered for this study and formed two groups of sprinters (7 ♂, 7 ♀) and physically active individuals (7 ♂, 7 ♀) of low-to-moderate levels of habitual physical activity (Table 1). Participants were required to have experienced no Achilles tendon pain or injury in the previous six months. Female participants were required to be taken the combined monophasic oral contraceptive pill for ≥6 months and were only tested between days 7-21 of pill consumption to limit fluctuations in endogenous gonadal hormones

(Onambele, Burgess, & Pearson, 2007). This helped control for the possibility of the menstrual cycle phase influencing neuromuscular function.

Table 1. Demographics of the sprinter and physically active groups

	Age (years)	Height (cm)	Mass (kg)	IAAF points (PB)*
Sprinters	22 ± 2	176.8 ± 10.3	74.0 ± 19.2	959.1 ± 90.8
Physically active	25 ± 1	170.1 ± 6.5	68.5 ± 7.1	-

*Sprinters main event distances: 60/100 m (n = 7), 100 m H (n = 1), 200 m (n = 2), and 400 m (n = 4)

Overview: Participants lay prone in an isokinetic dynamometer chair (Con-trex, Dubendorf, Switzerland) and performed voluntary isometric explosive and maximal contractions of the plantar flexors of the right leg. Both contraction types were performed at three ankle joint angles (-10° plantar flexion (PF), 0° (AZ), 10° dorsiflexion (DF)). The dynamometer fulcrum was perpendicular to the lateral malleolus of the ankle and the knee was at 180° (full extension). The ankle was fastened with ankle straps and shoulder straps were used to secure the upper body. The torque signal was sampled at 2000 Hz using an external A/D converter and interfaced with LabChart 8 software (AD Instruments, Sydney, Australia).

Protocol: Measurements were completed in the following order at the three joint angles.
1) Explosive voluntary contractions: Explosive isometric voluntary contractions (n = 5) of the plantar flexors were performed at each ankle joint angle following a standardised warm-up of submaximal contractions. For each contraction, participants were instructed to relax and following an auditory electronic signal, plantar flex their ankle as “fast and hard” as possible with the emphasis on “fast” for approximately 1-1.5 seconds. The contraction at each joint angle with the greatest RTD 0-150 ms value and no countermovement was used for analysis.
2) Maximal voluntary contractions: Following a warm-up period of submaximal isometric contractions at ~60 and ~70% of MVT to condition the tendon, maximal isometric voluntary contractions (n = 3) of the plantar flexors were performed at each ankle joint angle. In response to an auditory signal, participants were instructed to plantar flex their ankle ‘as hard as possible without any concern for the rate of force development’.

Data analysis: The torque signal was low-pass filtered at a cut-off frequency of 20 Hz using a zero-lag fourth-order Butterworth filter. Torque signals were processed using a custom-written code in Matlab (R2019a, MathWorks, Massachusetts, USA) and torque onsets were detected manually using the criteria outlined by Tillin et al. (2010). Rate of torque development (RTD) from the explosive contractions was quantified for three 50 ms time windows (0-50, 50-100, and 100-150 ms) from torque onset. RTD for each time period at each joint angle was extracted from the trial that demonstrated the greatest RTD 0-150 ms value. RTD for each time window (change in torque/change in time (0.05 s)) was determined in absolute terms (Newton-meters per second). Relative MVT (N.m/kg) from the maximal voluntary contractions was defined for each joint angle as the greatest torque during any of the MVT’s at that particular joint angle, normalized to body mass.

Statistical analysis: Group means and standard deviations were calculated for all RTD time windows and relative MVT values across ankle joint angles. The normality of data was determined using Shapiro-Wilk’s test. Following this, a two-factor (angle x population group) ANOVA with repeated measures on the angle factor was performed for relative MVT. A three-factor (angle x time period x population group) ANOVA with repeated measures on the angle and time periods factor was performed for RTD. Pairwise comparisons with Bonferroni correction were performed when a significant interaction was detected. Statistical analysis was completed using SPSS version 26 (SPSS Inc., Chicago, IL), with significance set at $P < 0.05$.

RESULTS: 1) RTD. For RTD, significant main effects for angle ($P < 0.005$), time ($P < 0.001$), group ($P < 0.05$), and angle by time interaction on RTD ($P < 0.005$) were observed. Post-hoc revealed sprinters demonstrated greater RTD for $RTD_{0\text{-}50}$ (*P* = 0.000 – 0.005) and $RTD_{50\text{-}100}$ (*P* = 0.005 – 0.037) at each ankle angle (Figure 1). There were no significant differences observed for $RTD_{100\text{-}150}$ between groups at each ankle angle (P = 0.267 – 0.482).

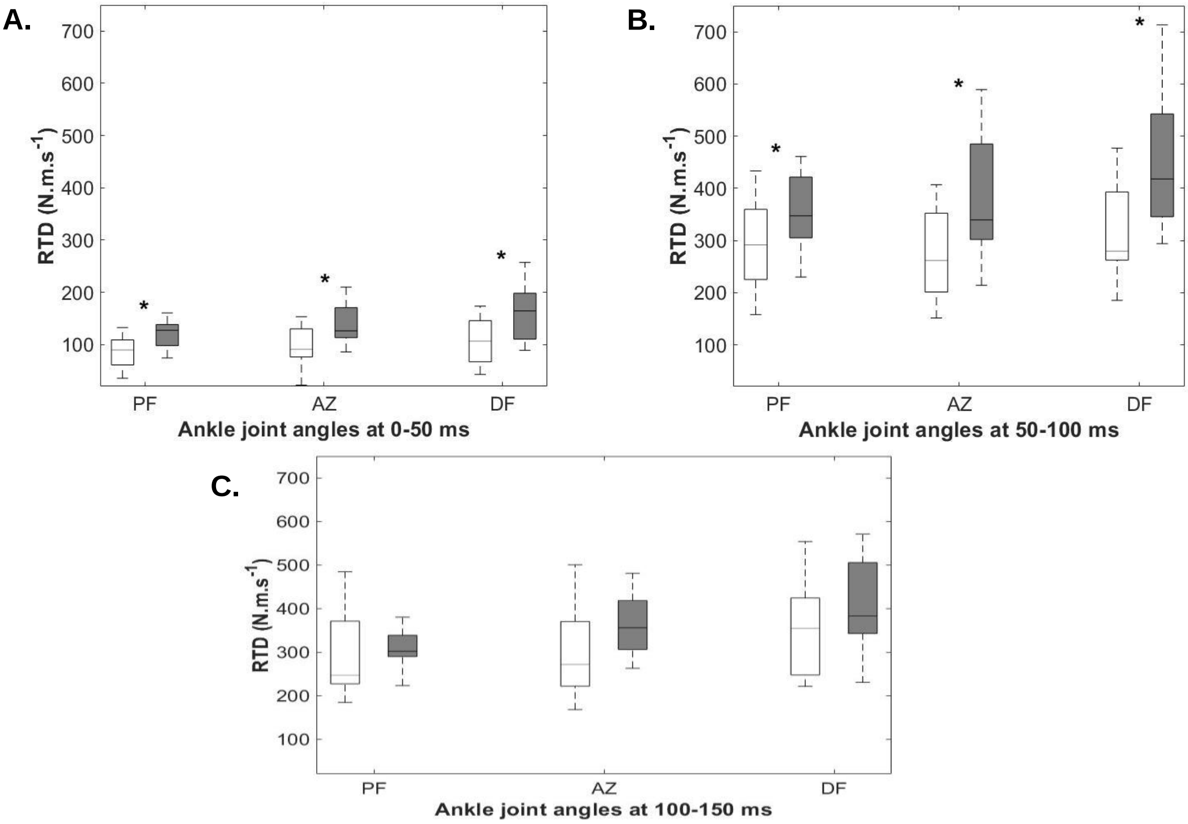

Figure 1: RTD across angles for physically active (white bars) and sprinters (grey bars), A) 0-50, B) 50-100, C) 100-150 ms. *Significant difference between groups at that angle (*P* < 0.05)

2) Relative MVT. Relative MVT had a significant main effect for angle (*P* < 0.001) with no significant group by angle interaction (*P* = 0.06). Relative MVT for both groups increased as ankle joint angle moved from PF to DF. Post-hoc revealed sprinters had a greater relative MVT at the DF (sprinters: 1.71 ± 0.42 N.m/kg, physically active: 1.40 ± 0.25 N.m/kg; *P* < 0.05) angle only.

DISCUSSION: This study examined differences in explosive performance of the plantar flexors in elite sprinters and physically active individuals across MTU lengths. The physically active group included participants who engaged in a range of training modalities, without a specific focus on sprint-specific training. By comparing this population with sprinters, we examined whether sprint-specific training specifically, induces adaptations in explosive torque production in the plantar flexors. Previous research reported no difference in the maximal rate of force development of the plantar flexors when comparing power-trained and endurance-trained athletes, tested at a single joint-angle configuration (AZ) (Kyröläinen & Komi, 1994). The present study observed that explosive RTD was greater in sprinters than physically active individuals during early phase RTD (0-50, 50-100 ms) across ankle joint angles. Differences in the training background of the control group (endurance vs physically active) may account for the varying results across studies. RTD in the later phase of explosive contractions is strongly influenced by the maximal force capacity of the muscle (Folland et al., 2014). Relative MVT was similar between groups at the PF and AZ angle, thus providing a rationale for the lack of difference observed between groups during late-phase RTD (100-150 ms) at these ankle joint angles. Sprinters are required to produce large amounts of force in a short period of ground contact time (~100 ms) during maximum velocity sprinting. Sprint-specific training, focusing on ballistic, high-velocity contractions has been demonstrated to increase neural activation during early phase RTD (Tillin and Folland, 2014; Van Cutsem et al., 2005). These training-specific adaptations may explain the differences between sprinters and physically active individuals in early phase RTD. Contractile RTD is influenced by many physiological parameters, thus, additional factors may have contributed to differences in early phase RTD between the groups such as muscle fiber type distribution (Harridge et al., 1996) or MTU stiffness (Bojsen-Moller, Magnusson, Rasmussen, Kjaer, & Aagaard, 2005). Sprinters demonstrated greater relative MVT at the DF angle only. The difference between groups at the DF angle may relate to the muscular demands of the plantar flexor MTU when sprinting. After rear block exit, during touchdown, the ankle dorsiflexes for the first ~40% of stance before plantar flexing (Charalambous et al., 2012). Increasing plantar flexor rotational joint moments has been suggested to improve performance by reducing the range of dorsiflexion the ankle goes through in early stance, thus increasing first stance power (Bezodis, Trewartha, & Salo, 2015). The higher relative MVT at the DF angle for sprinters may develop from the requirement for large plantar flexor joint moments in the dorsiflexion position during ground contact in sprinting. These results suggest that explosive-type training induces improvements in plantar flexor early phase RTD across MTU lengths, evidenced by enhanced RTD performance of sprinters. Training for sprinters should focus on maximising force production across MTU lengths of the plantar flexors. Also, improvements in MVT at dorsiflexed angles could contribute to improvements in joint power during the initial stance phase in sprinting.

CONCLUSION: Sprinters demonstrated improved early phase RTD (0-50, 50-100 ms) compared to physically active individuals across MTU lengths. Relative MVT at the DF angle was greater in sprinters, potentially due to the force specific-requirements of sprinting, particularly during the initial portion of the stance phase.

REFERENCES

Bezodis, N.E., Trewartha, G., & Salo, A.I.T. (2015). Understanding the effect of touchdown distance and ankle joint kinematics on sprint acceleration performance through computer simulation. *Sports Biomechanics,* 14, 232-245.

Bojsen-Møller, J., Magnusson, S. P., Rasmussen, L. R., Kjaer, M., & Aagaard, P. (2005). Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of the tendinous structures. *Journal of Applied Physiology*, 99, 986–994.

Charalambous, L., Irwin, G., Bezodis, I. N., & Kerwin, D. (2012). Lower limb joint kinetics and ankle joint stiffness in the sprint start push-off. *Journal of Sports Sciences*, 30, 1–9.

Folland, J. P., Buckthorpe, M. W., & Hannah, R. (2014). Human capacity for explosive force production: Neural and contractile determinants: Determinants of explosive force production. *Scandinavian Journal of Medicine & Science in Sports*, 24, 894–906.

Harridge, S. D. R., Bottinelli, R., Canepari, M., Pellegrino, M. A., Reggiani, C., Esbjörnsson, M., & Saltin, B. (1996). Whole-muscle and single-fibre contractile properties and myosin heavy chain isoforms in humans. *Pflügers Archiv*, 432, 913–920.

Kyröläinen, H., & Komi, P. V. (1994). Neuromuscular performance of lower limbs during voluntary and reflex activity in power-and endurance-trained athletes. *European Journal of Applied Physiology and Occupational Physiology*, 69, 233–239.

Maffiuletti, N. A., Aagaard, P., Blazevich, A. J., Folland, J., Tillin, N., & Duchateau, J. (2016). Rate of force development: Physiological and methodological considerations. *European Journal of Applied Physiology*, 116, 1091–1116.

Onambélé, G. N., Burgess, K., & Pearson, S. J. (2007). Gender-specific in vivo measurement of the structural and mechanical properties of the human patellar tendon. *Journal of Orthopaedic Research*, 25, 1635–1642.

Tillin, N. A., & Folland, J. P. (2014). Maximal and explosive strength training elicit distinct neuromuscular adaptations, specific to the training stimulus. *European Journal of Applied Physiology*, 114, 365–374.

Tillin, N. A., Jimenez-Reyes, P., Pain, M. T. G., & Folland, J. P. (2010). Neuromuscular Performance of Explosive Power Athletes versus Untrained Individuals. *Medicine & Science in Sports & Exercise*, 42, 781–790.

Van Cutsem, M., Duchateau, J., & Hainaut, K. (1998). Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *The Journal of Physiology*, 513, 295–305.

ACKNOWLEDGEMENTS: The authors would like to acknowledge the Irish Research Council for supporting this research.