THE RELATIONSHIP BETWEEN MAXIMAL AND EXPLOSIVE VOLUNTARY MUSCULAR TORQUE AND THE RESPONSE TO UNEXPECTED PERTURBATIONS

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The purpose of this study was to investigate the relationship between explosive torque of the plantar flexors and knee extensors and the centre of mass (COM) response to unexpected perturbations. 17 subjects were assessed for maximal and explosive isometric knee extension (KE) and plantar flexion (PF) torque and their response to unexpected anterior platform translations. The relationships between these measures were investigated using Pearson's correlation coefficients. Explosive torque of KE at 25 and 50 ms and PF at 50 and 75 ms demonstrated significant negative correlations (r = -0.528 to -0.575, $p < 0.05$) with COM acceleration at 300 ms post perturbation. This suggests that the ability to produce torque rapidly could assist in reducing and reversing the imposed COM acceleration following an unexpected perturbation.

KEYWORDS: neuromuscular function, sports injuries, dynamic balance

INTRODUCTION: Sporting participation has obvious physical, social and psychological benefits but also contains significant musculoskeletal injury risk (Bahr and Holme, 2003). Sports injuries occur very rapidly thus the ability to produce torque rapidly may be important in preventing their occurrence (Krosshaug et al., 2007; Tillin & Folland, 2013). The muscular ability to produce torque rapidly is commonly called explosive torque, explosive strength or rate of torque development and has been investigated in many populations and demonstrated to be a determinant of athletic performance (Tillin et al., 2013). There has been conflicting outcomes on the relationship between maximal muscular torque and balance measures (Lee et al., 2009; Lee et al., 2015). The ability of explosive athletes to respond more effectively to platform perturbations than endurance athletes has previously been demonstrated (Johnson and Woolacott, 2011); however, there has been minimal research into the relationship between neuromuscular measures of explosive torque and balance performance. Recent research has found significant relationships between explosive torque over the first 50 ms and sway index (Palmer et al., 2014). This would suggest that the ability to produce torque explosively may be related to balance performance abilities. However, injuries and falls occur in dynamic, unpredictable situations and often involve unexpected perturbations due to collision or impact. Therefore, relationships between explosive torque and static balance measures do not address the ability to respond to the unexpected dynamic perturbations that occur within sports. Accordingly, this study aims to investigate whether explosive torque measures of the knee extensors and plantar flexors can predict responses to unexpected perturbations. It was hypothesised that explosive muscular torque would predict COM response to unexpected perturbations.

METHODS: Following ethical approval, 10 recreationally active males (mean ± SD; age: 24.6 ± 5.5 years, height: 1.81 ± 0.10 m, mass: 81.9 ±10.4 kg) and 7 recreationally active females (23.3 ± 2.8 years, 1.69 ± 0.06 m, 63.2 ± 7.0 kg) volunteered for this study. Physical activity was assessed using the International Physical Activity Questionnaire. Exclusion criteria included any systematic strength or power training. All participants were healthy, injury free and provided written informed consent prior to their involvement.
Study Design: A cross-sectional study design was used with the participants visiting the laboratory on two occasions, separated by 5-10 days.

Experimental Setup: For plantar flexion (PF) measures participants were secured in an adapted commercial dynamometer (Contrex, Dubendorf, Switzerland) whilst kneeling with an additional custom built upright to support the anterior thigh and secure the proximal end of the shank. The fulcrum of the dynamometer was positioned in line with the lateral malleolus and the ankle was fixed at 90°. For knee extension (KE) testing participants were secured in a custom built dynamometer with hip and knee joint angles of 100° and 85° (where 180°= full extension) respectively. A 40 mm strap was placed 2 cm proximal to the medial malleolus in series with a calibrated u-shaped aluminium strain gauge positioned perpendicular to the tibia (coefficient of variation of the calibration coefficient <0.5%). For KE testing the force signal was amplified (x1000), for PF the signal was received from the Contrex via analogue output and both were sampled at 2000 Hz using an external A/D converter (Micro 1401; CED, Cambridge, UK) and interfaced with a computer using Spike 2 software (CED).
Protocol: KE and PF measurements involved a series of warm-up contractions at 50 and 75% of perceived maximum followed by three maximum voluntary contractions (MVC) each lasting 3 s interspersed with >30 s rest. Maximal force was defined as the greatest instantaneous force during any of the MVCs or explosive voluntary contractions (EVC). Participants then completed 10 EVCs of KE/PF, separated by 20 s rest, attempting to extend their knee and plantar flex the ankle 'as fast and as hard as possible' for 1 s with the emphasis on 'fast'. Contractions with pretension or a counter movement were discarded. EVC were performed until 10 valid attempts were completed. Explosive contractions were measured at 25, 50, 75, 150 and 200 ms from force onset. KE torque was calculated by multiplying force by participant's respective lever lengths while the Contrex dynamometer measured torque from the PF.
Perturbation Response Testing: All perturbation trials were completed on a CAREN system (Motek Medical, Amsterdam, Netherlands), with perturbations controlled by a custom script written in the Motek Medical D-Flow software. Kinematic data were collected using nine T20 Vicon (Vicon, Oxford Metrics Group, UK) cameras operating at 200 Hz. Fifty seven spherical markers of 14 mm diameter were used (Figure 2) to divide the body into 15 segments. Perturbation trials involved combinations of standing on one foot (right and left) with eyes open and closed. Four combinations of each (right/ eyes open, right/ eyes closed etc.) were completed resulting in 16 trials per subject. Only anterior platform displacements were analysed for this study but these were interspersed with backwards, right and left perturbations randomly ordered to ensure lack of predictability. Anterior platform perturbations had a maximum velocity of 0.45 $m.s^{-1}$ and magnitude of 0.1 m. Participants were instructed to stand with their hands by their side with the non-standing foot in a standardised position and asked to try to remain stationary and not to take a step in response to the perturbation. Motion analysis data were sampled at 200 Hz and low pass filtered with a fourth order zero lag Butterworth filter using a cut off frequency of 15 Hz. Centre of mass (COM) displacement and acceleration values were obtained from the initiation of perturbation to 500 ms post perturbation using Visual3D software (C-motion, Germantown, MD, USA) with values at 50 ms intervals used for further analysis. This sampling allowed for analysis of the early reflex response, electromechanical delay (EMD) and time from voluntary torque initiation until cessation of the perturbation.
Statistical Analysis: The relationship of KE and PF maximum voluntary torque (MVT) and explosive voluntary torque (EVT) (from 25-200 ms after contraction onset) with COM displacement (COMD) and COM acceleration (COMA) values (50 ms intervals up to 500 ms) were investigated using Pearson's correlation coefficients. Composite measures of right and left were used for statistical robustness and significance was set at $p < 0.05$.

RESULTS: KE MVT was 247.6 ± 80.8 Nm and PF MVT was 234 ± 60.4 Nm. No significant correlations were found between MVT or EVT and COMD measures. No significant correlations were found between MVT of PF or KE and COMA at any time point. However, significant negative correlations were found for KE EVT at 25 ms and 50 ms and PF EVT at 50 ms and 75 ms and COMA at 300 ms (r = -0.528 to -0.575, $p < 0.05$) indicating higher explosive torque values relating to lower COMA values. KE and PF EVT at other time points did not achieve significant correlations with COMA at 200– 300 ms (Table 1).

	Knee Extension Explosive Torque				Plantar Flexion Explosive Torque			
	25 ms	50 ms	75 ms	100 ms	25 ms	50 ms	75 ms	100 ms
COMA200 $m.s^{-2}$	0.049	0.088	0.119	0.170	-0.076	-0.046	-0.390	-0.027
COMA250 $m.s^{-2}$	-0.110	-0.120	-0.121	-0.121	-0.067	-0.072	-0.068	-0.062
COMA300 $m.s^{-2}$	-0.575*	-0.562*	-0.465	-0.424	-0.440	-0.560*	-0.528*	-0.381

Table 1. Correlation coefficients between KE EVT and PF EVT (Nm) from 25-100 ms and COMA ($m.s^{-2}$) from 200-300 ms. * $p < 0.05$.

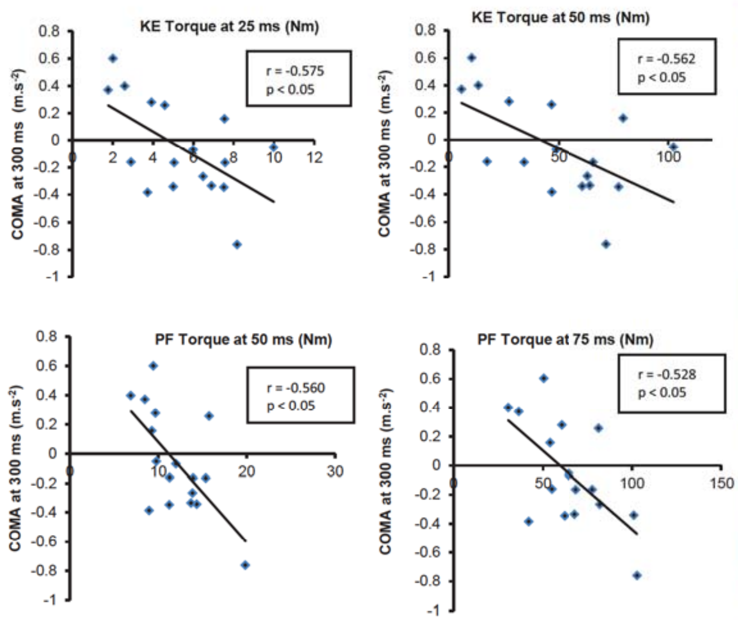

Figure 1. Relationships between KE EVT (Nm) from 25-50 ms and PF EVT from 50-75 ms and COMA ($m.s^{-2}$) at 300 ms.

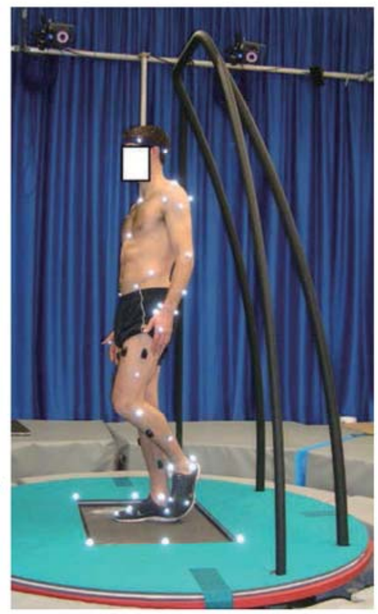

Figure 2. Lateral view of marker set up for perturbation testing.

DISCUSSION: The aim of this paper was to investigate whether explosive torque measures of the knee extensors and plantar flexors can predict response to unexpected perturbations. The results found significant correlations of KE EVT at 25 and 50 ms with COMA at 300 ms, and of PF EVT at 50 and 75 ms with COMA at 300 ms. These outcomes may be supported by previous research that found explosive athletes respond better to unexpected perturbations than endurance athletes but this study had no explosive torque measures (Johnson and Woolacott, 2011). Relationships between maximal strength and balance performance have been demonstrated previously (Lee et al., 2015) and also not demonstrated (Lee et al., 2009). As maximal torque can take more than 300 ms to produce it seems that explosive torque may be more pertinent in response to rapid stimuli such as unexpected perturbations and sports related injury mechanisms (Krosshaug et al., 2007; Tillin and Folland, 2013). The current results may be supported by previous research that found significant negative correlations between explosive torque and postural balance performance with higher explosive torque relating to lower postural sway index (Palmer et al., 2014). Izquierdo et al. (1999) also found a significant relationship between explosive torque and improved balance performance. However, both of these studies assessed balance performance using very different measures than the current paper making direct comparisons difficult. Considering response latency and electromechanical delay it is feasible that the initiation of restoring torque only commenced in response to perturbations after 150 ms. Restoring torque would then progress as rapidly as possible to slow and ultimately reverse the acceleration of the COM imposed by platform displacement. Therefore the effects of EVT becoming apparent at 250-300 ms would be consistent with restoring torque commencing 150 ms after perturbation initiation. It appears from the significant negative correlations between EVT of the KE and PF and COMA at 300 ms that the ability to produce torque explosively improves the ability to reduce and reverse the acceleration imposed on the COM by the platform perturbation and may indicate an improved performance in similar sporting situations. These results must be interpreted with cognisance of the relatively small subject numbers and large number of variables in the correlation. However, repeated significant correlations were consistently found in only a narrow range of variable combinations of early explosive torque measures and COMA at 300 ms, consequently adding credence to these findings.

CONCLUSIONS: It appears that the ability to produce torque rapidly may enhance response to unexpected perturbations. This may indicate that higher explosive torque capacity is useful in responding to external collisions and disturbances of balance, and may reduce injury risk in sporting situations.

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