THE EFFECT OF MEASUREMENT ANGLE ON APPROXIMATIONS OF MAXIMUM JOINT TORQUE

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The purpose of this study was to investigate the underestimation of maximum knee joint torque using a single joint-angle position for a variety of realistic torque-angle curves. The maximum force production capability of the knee flexors and knee extensors was modelled using literature-based parameters to define a quadratic torque-angle relationship. Model parameters were varied within a normative range and simulated measured torque was compared to true peak torque (model) for a series of commonly tested joint angles. Measurements furthest from the optimal angle for maximum strength were associated with underestimated torques that were 96% and 80% lower than true peak torque. Therefore, it is essential that knee joint torque is measured as close to the optimal angle as possible when attempting to determine maximum strength capability using a single discrete measurement.

KEYWORDS: muscle modelling, force-length profile, strength, knee

INTRODUCTION: The isokinetic dynamometer is considered the gold standard for measuring strength, however the ability to accurately detect the maximum force production capability of the muscles crossing the joint is dependent on methodology. A variety of experimental protocols exist yet, isometric peak torque is often measured at a knee flexion angle of 90° (Hori et al., 2020). Furthermore, despite a lack of consensus, many investigations rely on the peak torque achieved at a single joint angle (Blazevich et al., 2009; Konrad et al., 2021). However, the force-length and torque-angle profile of human strength has been shown to differ between individuals and muscle groups (Frasson et al., 2008; Herzog & ter Keurs, 1988; Herzog et al., 1991). Therefore, it is likely measurements to estimate maximum strength are made at suboptimal joint angles, which would result in a systematic underestimation in joint torque. Muscle modelling has been used more recently to provide insight into the effect of force-length characteristics on human movement (King Wilson & Yeadon, 2006), as it allows for the investigation of a single variable's effect on the system and can eliminate unavoidable measurement errors. Therefore, the purpose of this study was to model the effect of measurement angle when attempting to determine maximum torque for a range of typical torque-angle strength curves of the knee flexors and knee extensors.

METHODS: A two-parameter quadratic function employed by King, Wilson and Yeadon (2006) was used to describe the relationship between torque production and joint angle in a monoarticular representation of knee flexion and knee extension (Equation 1). Joint torques were computed as a percentage of true peak torque, such that true peak torque was equivalent to 100%. The joint angle representation was intended to be equivalent to agonist muscle length i.e., angles correspond to the posterior angle for knee flexion and the anterior angle for knee extension.

$$T_\theta(\theta) = \left(1 - k_2\left(\theta - \theta_{opt}\right)^2\right).100 \qquad \text{Equation 1.}$$

where $T_\theta(\theta)$ represents the normalised torque calculated using the torque-angle relationship, k_2 represents the width or curvature of the quadratic and θ_{opt} is the optimal angle for torque production.

Subject-specific parameters for optimal angle (θ_{opt}) and width (k_2) were extracted from the literature and used to derive a realistic set of isometric strength curves for the knee flexors and knee extensors (Table 1). Sources that provided both parameters together were given precedence.

Table 1. Joint torque-angle profile parameters

Article	Knee Flexion		Knee Extension	
	θ_{opt} (rad)	k_2	θ_{opt}(rad)	k_2
Felton (2015)	2.55	0.26	4.04	0.8
King, Lewis & Yeadon (2012)	3.12	0.39	4.22	1.64
King, Wilson & Yeadon (2006)	2.68*	0.08	4.28*	0.53

*Converted from paper to be equivalent to muscle length

The effect of measuring at suboptimal joint angles was assessed by perturbing the model parameters between minimum and maximum values from the literature. Intervals of 2° for θ_{opt} and 0.01 for k_2 were used, which resulted in a total of 672 different strength curve profiles for the knee flexors and 1232 for the knee extensors for each assessment. The effect of these perturbations was assessed for a series of commonly tested joint angles: 90°, 120° and 150° for knee flexion and 230°, 240° and 270° for knee extension (Horstman et al., 2009; Krishnan & Williams, 2014; Muanjai et al., 2020). To examine the effect of parameter perturbations on the model output, the difference between measured and true peak torque was calculated and reported in absolute (torque difference) and opposite terms (torque error). For interpretation purposes, the width parameter was converted to a meaningful measure, equivalent to the distance of the optimal angle to one of the roots of the quadratic in degrees (half range), where torque is equal to zero. Perturbations to the optimal angle are also described in relation to the measurement position, in degrees $(\theta - \theta_{opt})$.

RESULTS: The smallest overall torque differences were observed for measurement positions of 150° for knee flexion and 240° for knee extension (Figure 1). Following parameter perturbations, the largest underestimation of true peak torque occurred when measuring at 90° for knee flexion and at 270° for knee extension, with torque differences as large as 96% and 80%, respectively. Torque error between measured and true peak torque was smallest when torque was measured at the optimal angle and increased as the measurement position was displaced further from the optimal angle (Figure 2a). An increase in torque error was observed as the half range decreased, creating a narrower curve, and this effect was larger for measurement positions further from the optimal angle (Figure 2b). For knee flexion torque, the

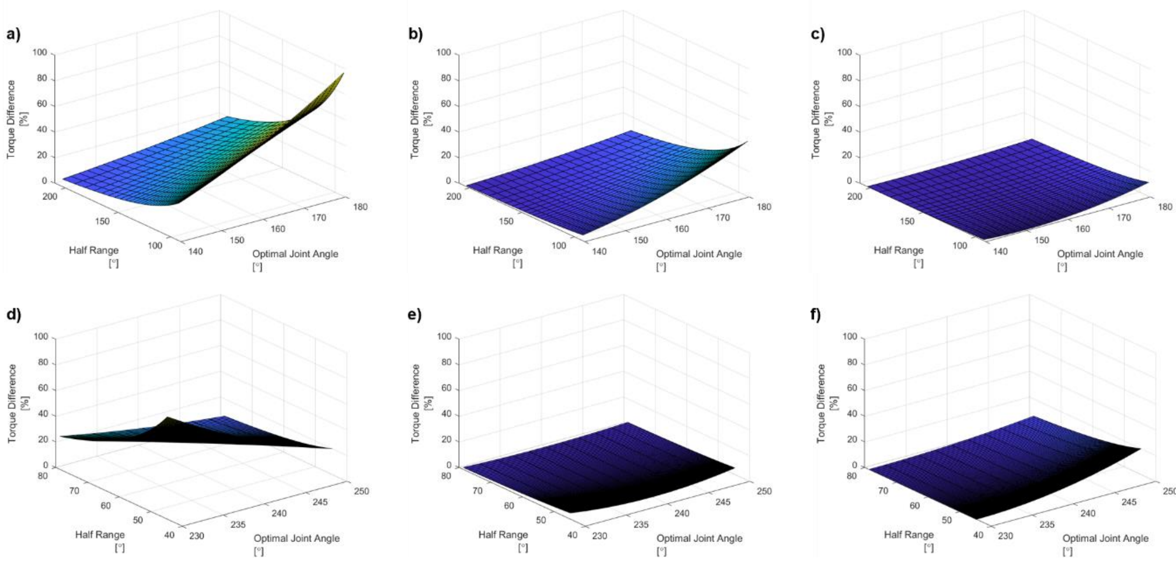

Figure 1. Differences between measured and true peak torque following perturbations to optimal angle and width for knee flexion measured at a) 90°, b) 120° and c) 150° and for knee extension measured at d) 270°, e) 240° and f) 230°

mean error across model perturbations increased from -1.8% (± 2.2, range: 10.7%) when measuring at 150° to -36.1% (± 19.3, range: 90.1%) when measuring at 90° (Table 2). For knee extension torque, the mean error increased from -1.3% (± 1.3, range: 5%) when measuring at 240° to -31.1% (± 16.1%, range: 73.5%) when measured at 270°.

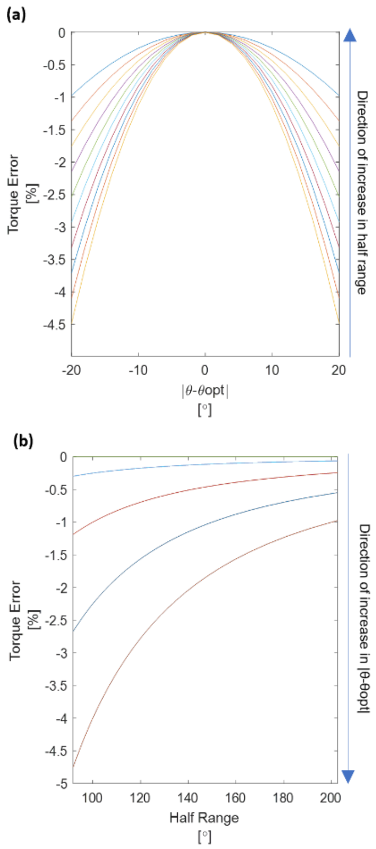

Figure 2. Effect of a) perturbations in the optimal angle for a range of widths and b) perturbations in the width for a series of optimal angles for knee flexion torque

DISCUSSION: The purpose of this study was to use perturbed models of human strength curves to examine the effect of using a single measurement location when attempting to determine true peak torque. When comparing measured torque at commonly tested angles to the true maximum torque production capability of the knee flexors and knee extensors, overall torque differences were smallest for knee flexion at 150° and knee extension at 240°, and thus it may be argued that the predictive power of these locations is better. In comparison, the largest differences may be observed for measurements at 90° of knee flexion (equivalent to 90° posterior angle, 270° anterior angle). This can be largely explained by the parameter bounds for the optimal angle which were defined from the modelling literature. These bounds constrained perturbations in the optimal angle to 140-180° for knee flexion and 230-250° for knee extension. Therefore, measurement positions further from the optimal angle resulted in larger overall torque differences and thus, larger errors in the measurement. This also coincided with larger variation and value ranges, indicating more scope for error when measuring torque further from the optimal angle and assuming it to represent maximal torque. Parameter bounds for the optimal angle indicate that the knee flexors are able to produce larger torque at more extended joint angles and thus, longer muscle lengths. This results in an ascending torque-angle profile with what appears like a plateau in torque production at more extended positions. In contrast, the torque-angle profile for the knee extensors is often described as an ascending-descending curve, whereby the optimal angle occurs near the middle of the range of motion. The effect of biarticularity on torque production, whereby maximum torque is a function of two joint angles rather than just one, indicates that the errors reported from this investigation may differ in the presence of changes to a secondary joint angle (Lewis et al., 2012; King, Lewis & Yeadon, 2012; Lewis, Yeadon & King, 2018). Therefore, hip joint angle should be considered when measuring knee joint torques, especially for the knee flexors where the contribution of biarticular muscles to net joint torque is larger.

Predictably, no torque error was observed for any variation in half range when the measurement position and optimal joint angle coincided. Torque differences and error

Table 2. Error between measured and true peak torque for commonly tested joint angles across a range of torque-angle curve widths

Joint Action	Joint Angle (°)	Torque Error (%)			
		Mean ± SD	Minimum	Maximum	Range
Knee Flexion	90	-36.1 ± 19.3	-6.1	-96.2	90.1
	120	-12.5 ± 9.0	-1.0	-42.8	41.8
	150	-1.8 ± 2.2	0.0	-10.7	10.7
Knee Extension	230	-4.6 ± 4.7	0.0	-20.0	20.0
	240	-1.3 ± 1.3	0.0	-5.0	5.0
	270	-31.1 ± 16.1	-6.5	-79.9	73.5

*Joint angle definitions: knee flexion (posterior), knee extension (anterior) increased as half range decreased from 203° to 92° for the knee flexors and from 79° to 45° for the knee extensors. These perturbations resulted in increasingly narrow torque-angle curves with smaller half range values. Therefore, reduced error can be expected when measuring torque at suboptimal joint angles from flatter torque-angle profiles, such as those of the knee flexors. As a result, comparatively small perturbations in the width of the torque-angle curve leads to greater error in the measured torque for the knee extensors as compared to the knee flexors.

In application, the differences in torque which might be associated with the measurement positions explored in this study would be further affected by typical measurement errors associated with isokinetic dynamometry. For example, misalignment of the knee joint and dynamometer axis can introduce errors in isometric torque of 0.3-17% and differences between the intended joint angle and true joint angle of 10-15° (Arampatzis et al., 2004). As such, the errors associated with single measurement positions will not only be limited by the effect of measuring at suboptimal angles, but also measurement error.

CONCLUSION: This study indicates that measuring torque at joint angles displaced from the true optimum joint angle, particularly for narrower torque-angle curves such as for the knee extensors, is associated with gross underestimation of torque producing capability. Therefore, when assessing strength using a single measurement angle, it is essential that joint torque is measured as close to the optimal joint angle as possible to ensure a close agreement between the measured value and true peak torque.

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