

EKSPERIMENTINIAI TYRIMAI

Power of performance of the thumb adductor muscles: effect of laterality and gender

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Key words: muscle contraction, power of adduction, thumb, hand.

Summary. The aim of this work was to originally measure mechanical power output of the thumb adductor muscles during fast adduction of the thumb in the horizontal plane. This information will contribute to biomechanical guidelines to help clinicians, sport medicine and rehabilitation specialists in the objective functional evaluation of abnormalities of thumb adductors. Participants performed 20 fast adductions in response to audio signals. Maximum and average angular velocity and angular acceleration were measured. Tangential components of these parameters were then derived. The force of adduction was obtained from the tangential acceleration and the mass of the rotational system. The power was then calculated as the product of the force of adduction and average tangential velocity during the acceleration phase of adduction. All young and untrained males and females were strictly right handed.

There was no significant difference in power between dominant and nondominant muscles for either males or females, but males developed significantly more power than females. Because adduction was performed at maximal speed, these data may be explained by the influence of parallel and series elastic elements in the muscle, as well as by influence of fast twitch fibers. Power may be used as a clinical index of the effectiveness of muscle contraction. The similarity of power outputs from dominant and nondominant thumb adductor muscles of right-handers can suggest a classical Bernstein approach. This theoretical approach purports that peripheral factors can distort central commands projected to dominant and nondominant extremities.

Introduction

Two intrinsic thumb adductor muscles (first dorsal interosseous (FDI) and adductor pollicis) are located in the dorsal interdigital space primarily attached to the medial border of the first metacarpal bone and the lateral border of the second metacarpal bone (1). As the largest intrinsic muscles of the hand, they are involved in specialized movements including clutching, gripping, or pinching actions (2–4). The muscles also contribute to the stability of the thenar compartment of the wrist and radio-carpal region (5). The thumb's intrinsic musculature contributes approximately 40% of the total intrinsic musculature of the hand (6). These muscles offer powerful rigidity to the wrist and usually work in mobilizing and stabilizing its segments (7).

Although the human hand performs as an integrated functional unit, examination of the role of its intrinsic muscles aids understanding of the movement in finger joints (8–10). Activity of the intrinsic muscles

of the hand often produces flexion of the fingers. As well, these muscles contribute highly to human manual dexterity and are involved with the spatial accuracy of movements of thumb (11) and proprioceptive accuracy of weight matching (12). If transitional movements of the fingers are performed in a faster (ballistic) way, the force of the contractile elements in the phasic contraction of the skeletal muscle is minimal according to the force–velocity relationship rule (13, 14). Because of the inverse relationship between force and velocity, *force does not form* a reliable index of effectiveness of muscle contraction. From mechanics, we know that power is equal to the product of force and velocity (15). The index of power (in comparison to the index of force) is considered as more integrated and reliable indicator of muscle contraction and power output (16, 17) and may be highly recommended for use as an important characteristic of muscle performance (18).

Apart from direct measurement of the velocity of shortening of hand muscles, investigations of force-velocity-power characteristics have mostly focused on the gross skeletal muscles of the upper (19) and lower extremities (18). Although the supposed maximal voluntary force of thumb adductor muscles has previously been investigated (20–22), there are no reliable data in the literature that illustrate the *power* of the thumb adductor muscles for the normal population when these muscles are located in a stable position in the same plane as that of the palm of the hand as has been recommended (21). Knowledge of the power of the thumb adductor muscles in a normal person enables establishment of a baseline to monitor the effectiveness of treatment of different abnormalities of this muscle as well as to identify the level of training of the muscle in relation to some specific kinds of sport, for example volleyball. Besides, there are no references in the literature regarding the functional asymmetry of the thumb adductor muscles in normal right-handed subjects. Thus, the aim of this work was to measure mechanical power output of the thumb adductor muscles during fast phasic contraction. This information will contribute to biomechanical guidelines to help clinicians and sport medicine and rehabilitation specialists in the objective functional evaluation of abnormalities of thumb adductors.

Material and methods

a. Participants' profile. A total of 24 unpaid volunteers, 11 males and 13 females, mostly undergraduate students and workers of Unitec New Zealand (Auckland, New Zealand) aged from 20 to 36 years (mode of 26 years), performed the task. All participants were naive to the task, classified as strongly right-handed (23), and were in good health. None had exceptional motor skills. The experiments were conducted at the Biomechanical Laboratory of Unitec New Zealand. This work has approval from the Ethics Committee of Unitec New Zealand.

b. Task. The task is based on fast adduction of the thumb. This is possible because the thumb has a highly mobile carpometacarpal joint (24). A device comprised of mechanical hardware connected to a personal computer was constructed for this experiment. The mechanical parts involve two simple levers, which are moveable within the arc of rotation of the thumb. A lever for each thumb is located within arc-like cutouts in the upper surface of the hardware. Each lever is connected to the axis of rotation through a transmission system. The rotation of the lever required negligible force to overcome friction (around 0.001 N).

Design of the hardware restricted the lateral adduction of the thumb to the horizontal plane. The participant was instructed to abduct the thumbs fully, laterally and extend the muscles to achieve the maximal angle (ideally equal to 90 degrees) between the thumb and the index finger of each hand. This abduction attempted to stretch the thumb adductor muscle fully in order to achieve potentially the maximum force of contraction according to the force-velocity relationship (25, 26). The participant received an auditory signal to commence adduction, pushing the levers with their thumbs. The point of contact was in the region of the center of the interphalangeal joint (Fig. 1). After completing these movements, the participant abducted the thumbs to their initial positions, and the levers automatically returned to these positions. Each participant adducted the levers 18 to 21 times. The period between adjacent starting signals was 10 to 15 seconds. Software identified and recorded the maximal angular velocity of the lever (Fig. 2).

c. Additional procedures and calculations. Each subject was weighed on electronic scales to measure total body mass. The masses of the segments of the upper extremity were calculated using regression equation (25). In this way, the fractional mass of the hand (M_{hand}) was obtained for each subject.

d. Basic analysis of data. The maximal angular velocity (ω_{max}) and average angular acceleration (α_{av}) were initially recorded. The indices were computed by the software from recordings at each 2 ms interval over the arc of motion of the lever from the initial point (ω_0) to the point of maximal velocity (ω_{max}).

Computed parameters:

1. The average angular velocity (ω_{av}) was expressed in rad/s and calculated using the formula:

$$\omega_{av} = \omega_{max} / 2$$

Where: ω_{max} is the maximal angular velocity expressed in rad/s.

2. The average radius of rotation of the thumb (r_{av}) in meters (from the point of the first carpal-metacarpal joint to the distal phalanx of the thumb) was calculated using the formula:

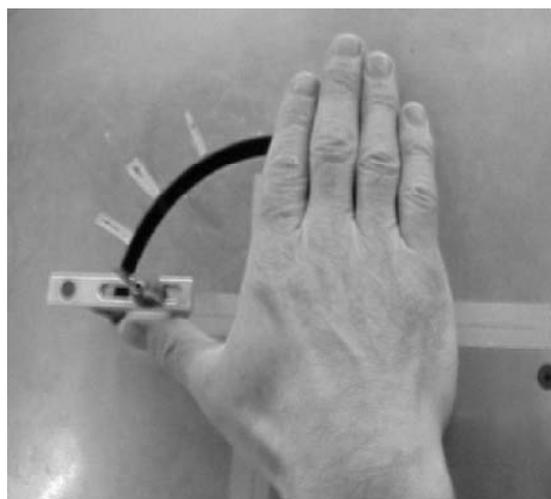
$$r_{av} = \alpha_{av} / \omega_{av}^2$$

Where: α_{av} is the average centripetal acceleration expressed in rad/s².

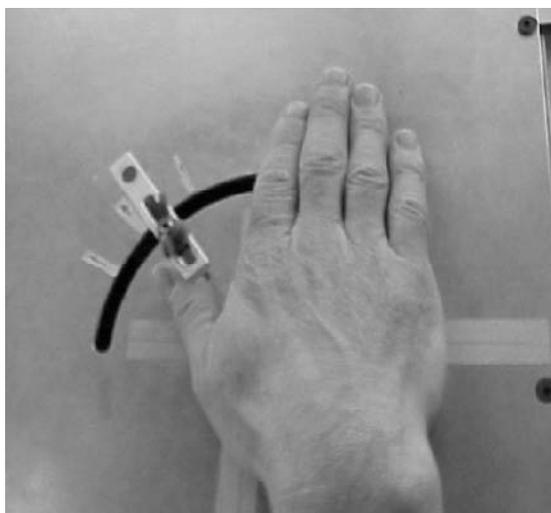
3. The average tangential velocity of the moving lever was calculated using the formula:

$$V_{av} = \omega_{av} \times r_{av}$$

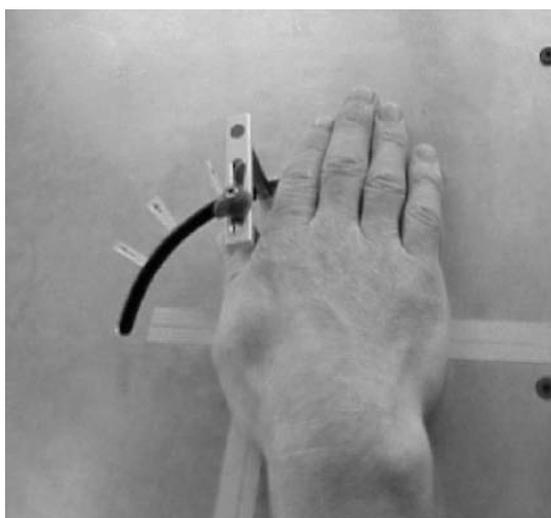
and expressed in m/s. This velocity describes the tangential velocity of the movement of the interphalangeal joint of the thumb at the point of application to the lever.



a



b



c

Fig. 1. Experimental adduction of the thumb

a – starting position; b – during adduction;
c – final position.

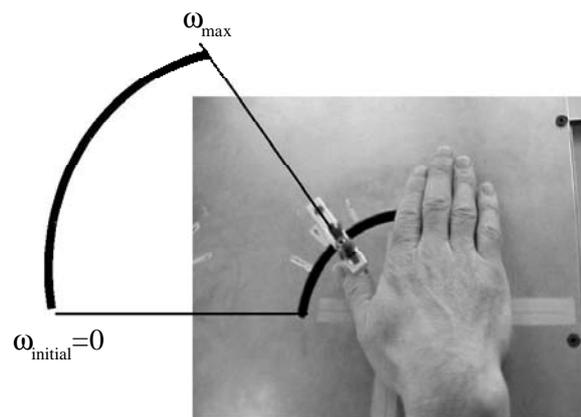


Fig. 2. Position of maximum angular velocity

Software detected the maximal angular velocity (ω_{\max}). The motion was initiated from rest ($\omega_{\text{initial}}=0$).

4. The average tangential acceleration of the moving lever was calculated as:

$$a_{\text{av}} = \alpha_{\text{av}} \times r_{\text{av}}$$

and expressed in m/s^2 . This acceleration describes the tangential acceleration of the movement of the interphalangeal joint of the thumb at the point of application to the lever.

5. The force applied to the lever (F) was calculated using Newton's Second Law:

$$F = (m_{\text{thumb}} + m_{\text{lever}}) \times a_{\text{av}}$$

Where: m_{thumb} is mass of the thumb (in kg); m_{lever} is mass of the lever (equal to 180 g or 0.18 kg).

Because there is no regression equation for calculation of the mass of a thumb, we approximated the mass of the thumb (including its soft tissue) as:

$$m_{\text{thumb}} = m_{\text{hand}} / 5$$

This fractionation was made because the human hand can be considered as five metacarpal-phalangeal digits (with osseous and soft tissues), and the moving segment of the thumb includes phalangeal and metacarpal bones with attached muscular elements.

6. The mechanical power of movement of the adducted lever (P) was calculated using the formula:

$$P = F \times V_{\text{av}}$$

and expressed in watts. This mechanical power is the average rate of energy used per second to move the combined mass of the thumb and lever. The rate of energy used is the rate of work done by or the power of the phasic contraction of the FDI and the adductor pollicis.

All individual and group average results were statistically analyzed using the one-way ANOVA method from the statistical computer software application "Minitab" (27).

Results

The raw individual data for linear velocity, linear acceleration, force, and power are presented in Tables 1 and 2.

For data reported in this section, F is the level of

significance returned by ANOVA, df is the degrees of freedom, and p is the probability.

There was no lateral difference between linear velocities of adduction of the thumb in females (F=0.06; df=1, 25; p=0.810). Males demonstrated greater

Table 1. Individual and group averaged results of young females

No.	Nondominant hand				Dominant hand			
	V _{av} (lin) m/s	a _{av} (lin) m/s ²	F N	P W	V _{av} (lin) m/s	a _{av} (lin) m/s ²	F N	P W
1	1.12	1.25	0.30	0.34	1.07	1.14	0.28	0.29
2	1.30	1.69	0.41	0.53	1.37	1.88	0.45	0.62
3	1.06	1.13	0.28	0.30	1.25	1.55	0.38	0.48
4	1.18	1.40	0.33	0.39	1.14	1.30	0.30	0.35
5	1.19	1.42	0.33	0.40	1.14	1.30	0.31	0.35
6	0.74	0.54	0.13	0.10	0.77	0.59	0.15	0.11
7	0.78	0.61	0.15	0.12	0.75	0.56	0.14	0.10
8	1.56	2.44	0.61	0.95	1.35	1.81	0.45	0.61
9	1.08	1.16	0.29	0.31	0.96	0.93	0.23	0.22
10	0.86	0.75	0.19	0.16	1.10	1.21	0.30	0.33
11	1.00	1.00	0.25	0.25	1.22	1.49	0.38	0.46
12	1.05	1.11	0.29	0.30	0.87	0.75	0.20	0.17
13	0.77	0.59	0.15	0.12	0.97	0.94	0.24	0.23
Av.	1.05	1.16	0.29	0.33	1.07	1.18	0.29	0.33
SD	0.23	0.52	0.13	0.23	0.20	0.43	0.10	0.17

Av. – average for the group; SD – standard deviation for the data.

Table 2. Individual and group averaged results of young males

No.	Nondominant hand				Dominant hand			
	V _{av} (lin) m/s	a _{av} (lin) m/s ²	F N	P W	V _{av} (lin) m/s	a _{av} (lin) m/s ²	F N	P W
1	1.16	1.35	0.36	0.41	1.31	1.79	0.47	0.62
2	1.00	1.00	0.25	0.25	1.49	1.11	0.28	0.42
3	1.54	2.38	0.61	0.94	1.86	1.79	0.46	0.86
4	0.67	0.45	0.12	0.08	0.60	0.58	0.15	0.09
5	0.72	0.52	0.13	0.09	1.37	1.30	0.33	0.45
6	1.50	2.24	0.61	0.91	1.80	2.26	0.62	1.11
7	1.35	1.83	0.50	0.67	1.64	1.48	0.40	0.67
8	1.03	1.05	0.28	0.29	1.84	1.58	0.43	0.79
9	1.30	1.70	0.44	0.57	1.61	1.81	0.47	0.75
10	1.40	1.96	0.55	0.77	1.88	2.00	0.57	1.07
11	1.35	1.83	0.46	0.62	1.95	2.61	0.65	1.28
Av.	1.18	1.48	0.39	0.51	1.58	1.66	0.44	0.73
SD	0.30	0.66	0.18	0.31	0.39	0.55	0.15	0.34

Av. – average for the group; SD – standard deviation for the data.

velocity of thumb adduction of the dominant hand ($F=7.13$; $df=1, 21$; $p=0.015$). Generally, irrespective of hand, males demonstrated greater velocity of thumb adduction than females ($F=12.56$; $df=1, 47$; $p=0.001$) (see Tables 1 and 2).

There was no lateral difference between dynamic forces of adduction of the thumb in females ($F=0.03$; $df=1, 25$; $p=0.867$) and males ($F=0.46$; $df=1, 21$; $p=0.505$). However, males demonstrated greater dynamic force of thumb adduction than females irrespective of hand ($F=10.07$; $df=1, 47$; $p=0.003$).

There was no lateral difference between powers of adduction of the thumb in both groups (females and males) ($F=0.00$; $df=1, 25$; $p=0.961$ and $F=2.7$; $df=1, 21$; $p=0.116$, respectively). Males demonstrated greater power of thumb adduction than females regardless of hand ($F=13.92$; $df=1, 47$; $p=0.001$).

Discussion

We investigated muscle power of the thumb adductor muscles of normal untrained, young right-handed participants. Our results demonstrated that velocity, dynamic force, and muscle power in males were greater than in females. Gender differences of skeletal muscle contraction force have been reported by other researchers (28). B. A. Phillips *et al.* (29) reported that males exerted a significantly greater force than females for the tested muscle group. P. Caserotti *et al.* (18) investigated the concentric phase of muscle contraction in older subjects during the stretch shortening cycle and found a lower power of contraction for women's leg muscles. Young males were significantly stronger than females in both voluntary and evoked force when maximal force of the adductor pollicis muscle was tested (30). Some authors explain this gender difference in muscle force by differences in the cross-sectional area of acting muscles (31). H. Kanehisa *et al.* (32) reported significant gender-related differences in muscle fasciculi. Relative to fasciculus length, males have thicker muscular elements than females. In the experiments by T. Ryushi *et al.* (33), slow twitch fiber areas were compared between physically active males and females, with females showing larger slow twitch fiber areas. Slow twitch fibers usually demonstrate less power in comparison to fast twitch fibers (34, 35). The authors clearly demonstrated the gender difference in force-time curves, indicating that the rate of maximal force development in females was lower than in the male group. This suggests that females may recruit their motor neural pool less effectively than males.

Power is the product of a force and velocity of motor performance. In turn, the velocity may be sug-

gested as a rate of shortening of a muscle during its force production. According to the conditions of our experiments, thumb adductor muscles of all our participants were initially maximally stretched, and thus they were able to produce potentially their greatest maximal force over time according to the length-tension relationship rule (13, 25, 36). However, because the rate of force production largely depends upon the rate of neural activation (37), it is likely that the slower rate of force production leads to lower force output during dynamic muscle action in our female participants. Alternatively, the greater power in males may be a result of structural differences in muscle elastic tissue between males and females (37, 38). The greater stiffness of male musculature may be attributed to higher levels of physical activity or daily activities that elicit a particular training effect (39).

We did not obtain significant group differences in muscle force and power between dominant and non-dominant muscles. In contrast to other researchers (40–43), we did not investigate the static isometric force but rather a dynamic explosive force during maximally fast contraction of the thumb adductor muscles while they were shortening. Some previous studies measuring the parameters of maximal voluntary force have shown a very low level of dominance of the “dominant” hand in experiments measuring grip strength (less than 10%) (42, 43). Other measures of “tip pinch,” “key pinch,” or “palmar pinch” (40) have demonstrated similar patterns. However, clinical investigation of the hand muscles has mostly focused on its maximal isometric force determined for integrated movements related to grip and pinch (44, 45).

Typically, the exerted control from the primary motor cortex of the left hemisphere is greater for the dominant extremity (46). The ignorable level of asymmetry of developed power in manual motor performance demonstrated by strong right-handed participants in our experiment may be also due to specific peripheral factors that distort the cortical influence in some right-hand dominant participants. For example, a smaller concentration of fast twitch fibers of some right hand adductors (47) or a smaller angle of inclination of the longitudinal axis of the FDI in relation to the rotary torque (48) or a smaller level of muscle stiffness and tone (49) in the dominant hand. Besides, the more trained and consequently more hypertrophic thumb adductor muscles of right-handers (50) may also produce a stronger braking effect for adduction during the decelerative phase in fast movement.

In contrast to D. Valour *et al.* (19), where power was determined from Hill's equation using the Herzog approach (13), in our experiment the power of muscle

contraction was calculated from direct measurements of force and velocity. However, our present data cannot answer questions regarding the possible maximal power developed by the thumb adductor muscles; it can only show us the power of the muscle during maximally fast concentric contraction while shortening.

In vivo, the contraction of the thumb adductor muscles is also influenced by the antagonistic muscles: abductor pollicis brevis and especially opponens pollicis. The design of our experiment ensures the recorded results are mostly related to contraction of the FDI and adductor pollicis muscles. The fast twitch fibers in this muscle are predominantly responsible for this type of the fast transitional movement (36). The dynamic force of fast explosive contraction is certainly increased by initial prestretching of the muscle in our experiment. When the prestretched muscle is concentrically contracting, its parallel and series elastic elements contribute to the power output of the contraction (13, 14, 26, 36).

Conclusions

Our results indicate the possibility of a baseline representing the power performance of the thumb

adductor muscles for young people. The variation in velocity is small for both males and females indicating that velocity may be used to provide an index related to the physical state of the thumb adductor muscles. The results of the mechanical power output of the thumb adductor muscles *in vivo* during concentric contraction at maximal velocity can illustrate a baseline for rehabilitation therapy for the first time. We did not find a significant lateral difference between magnitude of power of the left and right thumb adductor muscles during fast concentric contraction. We suggest that the generation of power from either hand may be used as a baseline in treatment of injury of the other hand. The similarity of power outputs from dominant and nondominant thumb adductor muscles suggests that peripheral factors can distort central commands projected to dominant and nondominant extremities.

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Rankos nykščio pritraukiamųjų raumenų galingumas: rankos dominavimo ir lyties poveikis

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Raktažodžiai: raumens susitraukimas, pritraukimo galingumas, nykštys, ranka.

Santrauka. *Darbo tikslas.* Originaliu metodu išmatuoti rankos nykščio pritraukiamųjų raumenų galingumą atliekant greitą nykščio pritraukimą horizontalia plokštuma. Šie duomenys reikalingi kliniciams, sporto medicams ir reabilitologams siekiant biomechaniniu požiūriu objektyviai įvertinti nykščio pritraukiamųjų raumenų funkcinę būklę ir patologinius pokyčius. Tiriamieji atlikdavo 20 greitų nykščio pritraukimų ir atitraukimų pagal garsinį signalą. Visiems tiriamiesiems matuoti maksimalūs ir vidutiniai išvestiniai greičio bei pagreičio dydžiai. Po to apskaičiuoti šių parametru išvestiniai tangentių komponentai. Pritraukimo jėga nustatyta vadovaujantis tangentių išvestiniais kampiniais pagreičiais ir rotacinės sistemos mase. Galingumas apskaičiuotas kaip jėgos ir kampinių pagreičių, susidaranciu nykščio pritraukimo greitėjimo fazėje, dydžių sandauga. Visi tiriamieji jauni ir netreniruoti vyrai ir moterys buvo tik dešiniarankiai.

Tyrimai parodė, kad nykščio pritraukiamųjų raumenų galingumas tiek dominuojančios dešinės, tiek ir nedominuojančios kairės rankos raumenų iš esmės nesiskiria nei vyrų, nei moterų, tačiau vyrai išvysto žymiai didesnę galingumą negu moterys. Kadangi rankos nykščio pritraukimas buvo atliekamas maksimaliu greičiu, todėl gauti duomenys gali priklausyti nuo nykščio raumenų elastingųjų elementų ir greitųjų raumeninių skaidulų. Rankos nykščio pritraukiamųjų raumenų galingumas gali būti svarbus rodiklis objektyvizuojant nykščio pritraukimo funkcinis pokyčius klinikinėje medicinoje bei reabilitacijoje. Dešiniarankių dominuojančios ir nedominuojančios rankos nykščio pritraukiamųjų raumenų vienodas galingumas patvirtina Bernšteino teiginį, kad visuma periferinių veiksmų gali iškreipti centrines komandas, projektuojamas dominuojančiai ir nedominuojančiai galūnei.

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