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EFFECTS OF ELBOW JOINT POSITION ON FOREARM SUPINATION TORQUE CONTROL AMONG YOUNG ADULTS

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ABSTRACT

Background: Large numbers of cases of pathological conditions in the forearm and elbow that have been reported in the literature are associated with tasks involving effort and repetitive movements of the arms and hands. Elbow position is known to affect the production of maximum forearm supination torque, and is a critical factor in designing appropriate therapeutic exercises. However, to our knowledge, there are no data on the effects of elbow position on tasks requiring control over submaximal torque levels. Objective: This study investigated the effects of elbow position on the production of maximum isometric forearm supination torque, and on constant and continuous torque control at different submaximal torque levels. Method: Sixteen young adults (24.7 ± 2.2 years old) were asked to perform two tasks: production of maximum lateral pinch torque (thumb and index finger) and controlled lateral pinch constant torque. Both tasks were evaluated at four different elbow positions (free position, 0°, 45° and 90° of elbow flexion) and three submaximal levels of lateral pinch torque production (20%, 40% and 60%). Maximal torque, variability, irregularity and accuracy of the motor response were used as dependent variables. Results: Greater torque values were found when the elbow joint was not restricted. The torque control tasks were not affected by the elbow position. However, greater variability and irregularity and lower accuracy in torque response were recorded with progressively increased submaximal torque levels. Conclusion: The results suggest that elbow position is not a determining factor for rehabilitation exercises that include torque control, in relation to forearm supination.

Key words: torque; elbow; control; supination.

RESUMO

Efeito da posição da articulação do cotovelo no controle de torque de supinação do antebraço em jovens adultos

introdução: Inúmeros casos de patologias em antebraço e cotovelo reportados na literatura estão associados com tarefas que envolvem esforço e movimentos repetitivos do braço e mão. A posição do cotovelo é conhecida por afetar a produção de torque máximo de supinação do antebraço, assim como é um fator crítico na determinação de exercícios terapêuticos apropriados. No entanto, baseado no que se conhece, não existem evidências sobre os efeitos da posição do cotovelo em tarefas que requerem controle de níveis submáximos de torque. Objetivo: Este estudo investigou o efeito da posição do cotovelo na produção de torque isométrico máximo de supinação do antebraço e no controle constante e contínuo de torque em diferentes níveis submáximos de torque. Métodos: Dezesseis jovens adultos (24,7 ± 2,2 anos de idade) foram solicitados a realizar duas tarefas: produção de torque máximo em pinça lateral (polegar e indicador) e controle constante de torque em pinça lateral. Ambas as tarefas foram avaliadas em quatro posições do cotovelo (livre, 0º, 45º e 90º de flexão) e três níveis submáximos de produção de torque em pinça lateral (20%, 40% e 60%). Torque máximo, variabilidade, irregularidade e precisão da resposta motora foram usados como variáveis dependentes. Resultados: Maiores valores de torque foram encontrados quando a articulação do cotovelo não foi restringida. O controle de torque não foi influenciado pela posição da articulação do cotovelo. Maior variabilidade, irregularidade e menor precisão na resposta de torque foram registradas com o aumento progressivo dos níveis submáximos de torque. Conclusão: Os resultados sugerem que a posição do cotovelo não é um fator determinante para exercícios de reabilitação que incluam torque em supinação do antebraço.

Palavras-chave: torque; cotovelo; controle; supinação.

INTRODUCTION

One of the greatest challenges for researchers in the field of motor control, with critical implications for physical therapy intervention, is to explain how a human neuromechanic system, with so many degrees of freedom, can be controlled by the Central Nervous System (CNS). The success of the performance of any task requires that the CNS control many redundant variables. For instance, if we consider the reaching movement and manual prehension required to turn a doorknob, different degrees of joint freedom must be controlled by the CNS. In addition to that, during static prehension of the fingers on the doorknob, the human hand allows infinite combinations of joint angles and of finger strength and moment of contact.

This phenomenon through which the CNS deals with more available possibilities in the system than really necessary to perform a task has been traditionally called motor redundancy[1-3]. In particular, manipulative tasks have been investigated in order to understand this inherent trait of the neuromotor system[4-8]. Because of its singular mechanical structure, the hand stands out as a "convenient" tool in the study of the problem of motor redundancy[9]. The hand consists of serial connections of the phalanges and also parallel aligments of the fingers which create kinetic and kinematic redundancy respectively[8,10]. Likewise, the serial connection of the segments that make up the upper limb is a source of kinetic and kinematic redundancy. For example, different joint positions of the shoulder and/or elbow can determine an individual's greater or lesser ability to manipulate a particular object.

In literature, there are reports that the production of maximum forearm supination torque is influenced by elbow position and that the greatest torque-generating capacity occurs in the positions in which the elbow is at greater flexion angles, decreasing as the elbow extends[11-13]. The effect on the capacity for maximum supination torque production has been described in literature; however there is no record, up to the present date, of studies on the effects of elbow position on submaximum torque control. Manipulative activities of daily life such as opening a jar or using cutlery at the table eminently require submaximum force and torque production, instead of maximum force and torque levels. Also, upper limb functional rehabilitation sessions require submaximum levels of forearm and finger rotational forces (torques) for the performance of therapeutic exercise.

The present study sought to investigate the effect of elbow position on the production of maximum isometric forearm supination torque as well as on the response of constant and continuous isometric control of different levels of submaximum torque. The following hypotheses were tested: a) the production of maximum torque in lateral pinch will be greater when the elbow joint is positioned at intermediate flexion levels (around 45º); b) the performance of torque control response in lateral pinch will be better at intermediate flexion level (around 45º); c) in finger pressure and two-fingered prehension tasks, force control response is better when tasks are performed at medium force levels (around 40% of maximum voluntary force)[14-16]; for that purpose, different submaximum torque control levels were also manipulated with the expectation that constant and continuous torque control in lateral pinch would improve as torque levels were required at 40% of maximum torque.

MATERIALS AND METHODS

Sixteen young adults of both genders (9 men and 7 women), aged 20 to 30 (24.7 ± 2.3 years) participated as subjects in this study. All participants were classified as right-handed according to preferential hand use to eat and write and did not have a history of upper limb trauma or neuropathy. The anthropometric data for each group are specified in Table 1. Hand length was measured from the tip of the distal extremity of the middle finger to the lunate bone[17]. Hand width was measured between the metacarpophalangeal joint of the index and the little finger[17]. All participants agreed to be part of the study and signed the written informed consent approved by the Ethics Committee of Universidade Federal do Rio Grande do Sul – Process number 2005-509.

Two tasks involving isometric supination torque (TQ) in lateral pinch (using the thumb pad and the radial side of the second phalanx of the index finger) were assessed with a customized torque transducer[4,18,19]. Subjects were asked to perform two isometric tasks: maximum

Table 1. Subject's age, weight, height, hand length and hand width. Group mean values and standard deviations are shown.

	Age (years)	Mass (kg)	Height (cm)	Hand length (cm)	Hand width (cm)
Male (n=9)	24.4 ± 1.8	77.3 ±11.3	173 ± 7	18.6 ±0.8	8.2 ± 0.2
Female (n=7)	25.1 ± 2.8	60.0 ± 7.2	167 ± 7	17.7 ± 0.5	7.3 ± 0.5

voluntary torque in lateral pinch (TQ_{MAX}) and constant and continuous torque in lateral pinch (TQ_{CONST}). The lateral pinch movement (thumb and index finger) was used because many daily manipulative activities involve independent control of the fingers, especially the thumb and the index finger. All subjects were asked to maintain, for 15 seconds, constant and continuous isometric torque in three submaximum levels of maximum torque (20%, 40% and 60%). Submaximum torque levels were displayed on an oscilloscope screen, used as online visual feedback, in which a fixed horizontal line indicated the target torque and another mobile horizontal line represented the torque produced by the subjects. Both tasks were performed at distinct elbow joint angles (0º, 45º and 90º of flexion) and in a free position. The free position was included in the protocol so that an experimental condition, without restriction to the angle of the elbow, could be used as reference. Except for the free position, the upper limb was mechanically restricted by stiff, adjustable-height, gutter-shaped braces that constrained the elbow joint to the predetermined angles. Velcro® tape held the upper limb to the brace, maintaining the stability of the other upper limb joints. The predetermined angles were reassessed using a goniometer. In all positions, the shoulder was positioned at approximately 80º of abduction in the scapular plane and approximately 20º of internal rotation, radioulnar joint was positioned at approximately 80º of pronation and wrist extension of approximately 20º. The scapular plane was set at 30º anterior to the frontal plane (Figure 1). Each attempt started with a "ready" signal, and the subject was instructed to position the mobile line over the target line fixed at each level relative to maximum torque. The tested positions and the submaximum torque level were randomly presented to the subjects.

The transducer response signal was amplified by a signal conditioning unit (ENTRAN MSC6), converted by an A/D board (Dataq Instruments, Inc. Akron, USA) and sampled at 500 Hz. The data were acquired by a Pentium 200 PC. Acquired signals were smoothed (low-pass, second order Butterworth filter) with cut-off frequency of 25 Hz[4,19]. During the TQ_{MAX} task, the peak torque produced was selected as maximum. In the TQ_{CONST} task, the five initial seconds of each attempt were removed in order to exclude the initial adjustment period of the torque to the visual feedback. Mean, standard deviation (SD), approximate entropy (ApEn)[20] and RMS error (RMSe) were input as dependent variables in the 10 remaining seconds. The data were processed in Matlab® (Matlab 5.3, MathWorks, Inc.) using a piece of software written specifically for this study. The $ApEn^{m,r}$ value was calculated using a period length of m= 2 and width filter of r= 0,2*SD.

After verifying data normality, we used standard descriptive statistics and ANOVA for repeated measures, with POSITION factor [4 levels: free, 0º, 45º, 90º] and TORQUE LEVEL factor [3 levels: 20%; 40%; 60%]. *Post hoc* tests (Tukey) were calculated to identify the differences between factors. Sphericity tests were performed and appropriate correction was made for cases in which significant levels were found. Contrast tests were reported in the description of results for factors which had their effect discarded. Significance levels of $p< 0.05$ were adopted.

RESULTS

The results showed that, in general, different elbow angles had no effect on the torque control response at submaximum levels. However, when participants were asked to perform the TQ_{MAX} task, significantly higher maximum torque values were found in the free position (1.0 Nm ± 0.3) compared to the elbow extension position

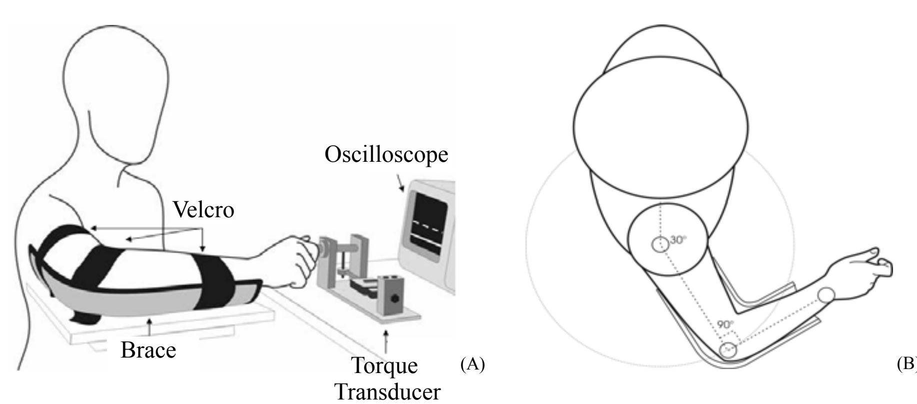

Figure 1. (A) Experimental settings including the lateral pinch torque task and the mechanical constraint (brace) at 90º of elbow flexion. (B) Overhead view of the shoulder and elbow joint positions during TQ_{MAX} and TQ_{CONST} performance.

(0.8 Nm ± 0.3), 45º of flexion (0.9 Nm ± 0.3) and 90º of flexion (0.9 Nm ± 0.3). These results were confirmed by ANOVA which displayed an effect for the position factor in TQ_{MAX} [Wilks' Lambda 0.196 F(3.13) = 17.743; p< 0.001] which revealed a difference in the free position compared to the other positions (p< 0.05).

The torque mean produced in each of the tested positions in the TQ_{CONST} task confirmed that required submaximum torque levels were performed differently by the subjects (Figure 2A). ANOVA only revealed an effect for torque levels [Wilks' Lambda 0.089 F(3.13)= 11.161; p< 0.001] and did not reveal an effect for position. There was no interaction between factors. The contrast test showed a significant linear trend (p< 0,001), i.e. mean torque increased as higher submaximum torque levels were required. Differences were found in the comparison of all levels (p< 0.05).

Motor response precision was measured using RMS error. The error increased as higher submaximum torque levels were required (Figure 2B). ANOVA results did not reveal an effect for joint position, however they revealed an effect for submaximum torque percentage levels [Wilks' Lambda 0.402; F(2.14)= 10.412; p< 0.002]. There was no interaction between factors. The contrast test showed a significant linear trend (p< 0.001), confirming the relationship between variables. *Post hoc* tests (Tukey) displayed significant differences in elbow extension torque control between 20% and 60% torque levels (p<0.001), in 90º flexion torque control between 20% and 60% torque levels (p< 0.001) and between 40% and 60% torque levels (p< 0.027). There were no differences in the free position and the 45º flexion position.

Variability in torque control response was measured with the standard deviation of the continuous and constant phase of the TQ_{CONST} task, and there was no variation among tested positions. However, when participants were asked to perform different submaximum levels of torque, variability increased in the higher torque control level, as shown in Figure 2C. These findings were confirmed by ANOVA, which only revealed an effect for torque levels [Wilks' Lambda 0.183 F(2.9) = 20.026; p< 0.001]. There was no interaction between factors. The contrast test showed a significant linear trend (p< 0.001), meaning that, as relative torque level increased, there was a linear increase in torque control variability. *Post hoc* tests (Tukey) showed a difference in torque control variability for the free position and the elbow extension position between 20% and 60% torque levels (p< 0.001); in the 45º position between 20% and 40% torque levels (p< 0.029), between 20% and 60% torque levels (p< 0.001) and between 40% and 60% torque levels (p< 0.013). When the elbow was positioned at 90º flexion, significant differences were found between 20% and 60% torque levels (p< 0.001) and between 40% and 60% torque levels (p< 0.001).

Motor response irregularity results were measured using ApEn and the results showed that torque control

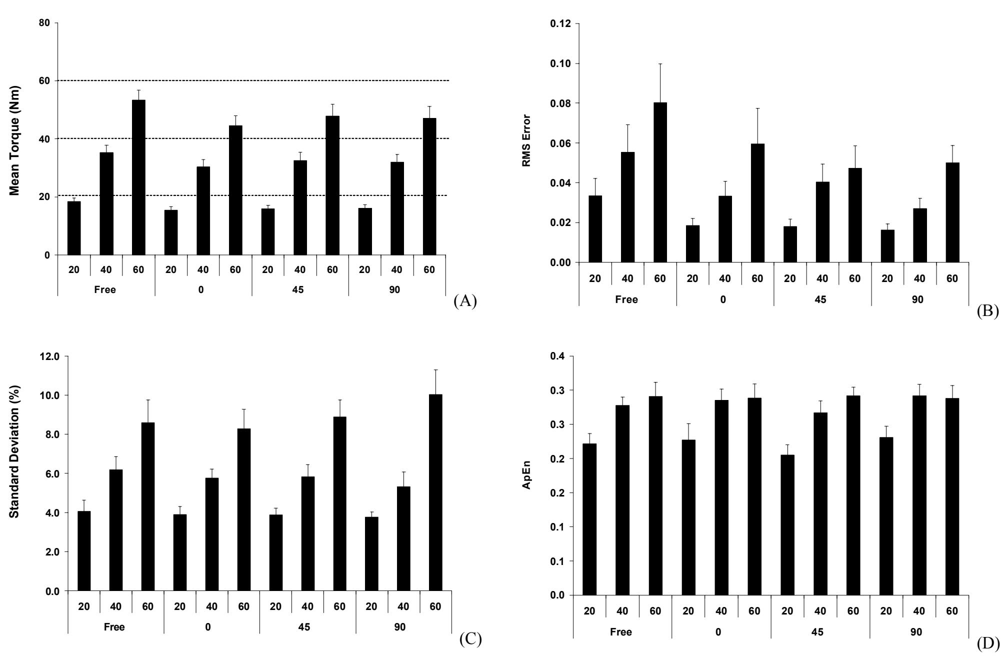

Figure 2. Mean torque (A), normalized RMS error (B), standard deviation (C) and approximate entropy (D) during the TQ_{CONST} task across different levels of submaximum torque (20%, 40% and 60%) and elbow position (free, 0º, 45º and 90º). Averaged group data are shown with standard error bars.

became more irregular as higher submaximum torque levels were required. ANOVA supported these results and did not reveal an effect for joint position, however it did show an effect for submaximum torque levels [Wilks' Lambda 0.385 $F(2.14)= 11.204$; $p< 0.001$]. The contrast test also showed a significant linear trend ($p< 0.001$) for this variable, i.e. as torque percentage increased, there was a linear increase in torque control irregularity. *Post hoc* tests (Tukey) showed that irregularity differed in free position torque control between 20% and 40% torque levels ($p< 0.047$) and between 20% and 60% torque levels ($p< 0.011$). In the elbow extension position, there were differences between 20% and 40% torque levels ($p< 0.041$) and between 20% and 60% torque levels ($p< 0.037$); in the 45º flexion position, between 20% and 40% torque levels ($p< 0.017$) and between 20% and 60% torque levels ($p< 0.001$). In the 90º flexion position, there were differences between the 20% and 40% torque levels ($p< 0.041$) and between the 20% and 60% torque levels ($p< 0.05$) as shown in Figure 2D.

DISCUSSION

This study analyzed the effect of elbow joint position on maximum response and control of isometric supination torque. The results showed, in general, that torque control response was not influenced by the position of the elbow joint, whereas greater variability, greater irregularity and less precision were registered with gradual increase in torque levels for motor control response of the studied task. In addition to that, the highest torque production occurred in the subjects' preffered position, when the elbow joint was not restricted at experimentally predetermined joint angles.

The highest torque production achieved in the free position can be explained by the neuromechanical properties of the elbow and forearm muscles involved in the task. Subjects were asked to perform an isometric supination torque in lateral pinch, and although isometric, the task involved muscles that cross the elbow joint, such as the biceps brachii, brachioradialis and supinator. Bechtel and Caldwell[11] reported higher supination torque values when the elbow was flexed at 90º and a gradual torque decrease with the extended elbow[11]. Significant effects of the elbow angles on maximum torque production have been reported when the forearm is positioned at 75% pronation and the elbow is flexed at 135º[13]. Also, it has been reported that supination peak torque occurs when the elbow is flexed at 85º and goes down to 48% when the elbow is flexed at 45º[21].

Even if the mentioned studies differ as to the relationship between maximum torque and elbow and forearm angle, they point to the fact that a great torque-generating capacity occurs when the elbow is positioned at greater flexion angles, i.e. above 80º. Previous studies also agree that this capacity decreases as the elbow extends. This present study found distinct results. The elbow was also tested at 0º (or total extension), 45º and 90º flexion; however there was no difference between tested positions. The braces used to restrict the elbow joint at predetermined angles may have partially and mechanically limited the action of the agonist muscles. Neuromuscular strategies used previously by the subjects may have resulted in greater torque production in this position.

Even though the flexor action of the biceps brachii over the elbow joint was not directly assessed in this study, the role of this muscle on isometric forearm supination during the performance of the TQ_{MAX} task was important. Because it is a biarticular muscle, the biceps brachii is responsible for the transmission of power or energy through the elbow joint and for positioning the upper limb. When it comes to elbow flexor and extensor torque production, it is widely known that the isometric capacity of muscles that cross the elbow joint depends both on architectural differences (especially the area of physiological transversal section and the optimum length of muscle fascicles) and on moment arm (distance between the muscle's line of action and the center of joint rotation) of the muscles involved in the action[22]. Considering the fact that torque magnitude is the product of the strength of a single muscle or group of agonist muscles and the respective moment arm, it is possible to draw inferences about the muscle strength-length relationship through the torque-angle relationship. It has been established that, for elbow flexors, moment arm is higher in an intermediate position, i.e. elbow joint at around 90º of flexion[21,23], above 80º of flexion and around 100º of flexion[24,25] and lower at total extension and total flexion[23]. Because the moment arm for the majority of muscles changes throughout its movement amplitude, muscle torque is often at its maximum in an intermediate elbow position[23]. Despite contrasting results between the present study and previous studies, it appears that flexion angles above 45º supply the muscles with greater torque-generation capacity at flexion as well as at supination.

Besides maximum torque, motor response during the continuous and constant isometric torque task was assessed as to the different joint positions and submaximum torque levels. The results did not indicate an effect of elbow joint position on torque control response. However, when participants were asked to control torque at different submaximum levels, there was greater motor response variability. These results concur with findings of previous studies for tasks involving finger-pressure strength control[26], two-fingered prehension in pinch[14] and torque in lateral pinch[4,19].

The present study also investigated the time for torque response variability using torque sinal regularity (ApEn) to assess the system's response predictibility over time[20]. This analysis offered information on the sensory and motor system's ability to adjust itself and explore the control possibilities of the motor system[27,28]. The results for the present study showed the effect of irregularity on assessed submaximum torque levels and converged with the findings of previous studies[18,26,28,29]. There was an increase in irregularity until the maximum point (40%), when there was a decrease to smaller values of approximate entropy. This study found differences between 20% and 40% torque levels and between 20% and 60% torque levels, meaning that as higher torque levels were required, greater system flexibility was needed, up to a certain point, when irregularity seemed to have stabilized.

Motor response precision suffered the effect of torque levels, proving that failure to reach the task target increased as higher submaximum torque levels were required. These findings agree with those of previous studies[26,30], which also reported less precision at higher strength levels. RMS error, used as a precision measure, reflected the subject's difficulty in reaching the target which, in this case, meant reaching the relative torque level required and keeping it constant and continuos. Although there was no evidence of an effect of elbow position on torque control response, there was evidence of a trend for higher values for this variable in the free position in all submaximum torque levels when compared to the other positions. The brace that was used to restrict elbow angles may have had a stabilizing effect on the gravitational torque generated by the mass of the segment compared to the free position in which the limb remained suspended while the subject performed the task.

Even though there was no video recording of the task during data collection, we found that subjects generally flexed the elbow at approximately 45º, based on the qualitative observation of their free position.

CONCLUSION

The results of this study led to the following conclusions: a) the maximum production capacity of forearm supination torque is more closely related to the neuromuscular strategies used by the subjects than to the mechanical position of the elbow joint; b) the position of the elbow joint does not influence forearm supination torque control; c) greater forearm supination torque levels require more complex neuromotor adjustments in the sensory and motor system.

One of the limitations of the present study was the potential interference of the mechanical device (gutter-shaped brace) during task performance. The use of video recording would allow kinematic parameter measurements with greater precision and without interferences in the motor task performance itself. Nevertheless, the results reported in this study have implications for physical therapy and ergonomics that cannot be ignored. In general, these findings suggest that, in forearm movement rehabilitation, elbow joint angle variations have no direct clinical implications on tasks that aim for motor response precision. However, elbow position is critical for daily tasks in which maximum torques are required. In addition to that, the results reported in this study provide information that is relevant to the production of ergonomic models that involve elbow strength and maximum and submaximum torque.

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