DOI: 10.1590/1809-2950/17016425012018

ORIGINAL RESEARCH

Influence of static wrist orthosis on muscle activity and shoulder and elbow range of motion during a functional task: a biomechanical study

Influência da órtese estática de punho na atividade muscular e amplitude de movimento de ombro e cotovelo durante uma tarefa funcional: estudo biomecânico

Influencia de la ortesis estática de puño en la actividad muscular y la amplitud de movimiento de hombro y codo durante una tarea funcional: el estudio biomecánico

André David Gomes[1], Flávia Pessoni Faleiros Macedo Ricci[2], Ana Carolina Zampar[1], Paulo Roberto Pereira Santiago[2], Marisa de Cássia Registro Fonseca[1,2]

ABSTRACT | Orthoses are therapeutic resources that are appropriate to protect and remedy deformities or to help in the performance of certain functions; however, its use may lead to proximal compensations in the shoulder. Thus, this study aims to evaluate the influence of dorsal static 30° extension orthoses on the shoulder and elbow biomechanics in 25 asymptomatic individuals during a functional task. The range of motion and muscle activation was collected by simultaneous and synchronized analysis during the Elui functional test related to feeding, under the conditions with and without the orthosis. In order to allow a comparison of the different subjects and muscles, the data were analyzed by EMG signal of each muscle and, for kinematic analysis, pre-defined marker coordinate systems were constructed. The captured signals were filtered and processed by custom software, and the t-test for paired samples, SPSS® software, p<0.05, was used. We found significant increase in activation of the anterior deltoid and pectoralis major muscle in the reach phase and upper trapezius, anterior and posterior deltoid in the release phase with the orthosis. The kinematic analysis showed a significant increase in the range of motion of shoulder abduction movements, elbow flexion and pronation in the displacement phase and shoulder extension and elbow flexion movements in the release phase. Our findings suggest that the use of static wrist orthosis while performing a task can lead to compensations, with predominant activation of more proximal muscles of the upper limb.

Keywords | Activities of Daily Living; Electromyography; Biomechanical Phenomena; Upper Extremity; Orthotic Devices.

RESUMO | As órteses são recursos terapêuticos indicados para proteger, corrigir deformidades ou auxiliar em certas funções; porém, seu uso pode acarretar compensações proximais no ombro. O objetivo deste estudo é avaliar a influência da órtese estática dorsal do punho, em 30° de extensão na biomecânica do ombro e cotovelo, em 25 voluntários assintomáticos durante uma tarefa funcional. Os dados da amplitude de movimento e ativação muscular foram adquiridos de forma sincronizada e simultânea durante parte do teste funcional Elui, que simula alimentação, dividida em alcance, deslocamento e liberação, de uma jarra, nas condições sem e com órtese. Para possibilitar a comparação entre os diferentes sujeitos e músculos, os dados foram analisados pela integral do sinal EMG de cada músculo e, para análise cinemática, foram construídos sistemas de coordenadas de marcadores pré-definidos. Os sinais captados foram filtrados e processados por um *software* personalizado, e utilizou-se o teste t para amostras pareadas – *software* SPSS, p<0,05. Notou-se um aumento significativo da ativação dos músculos deltoide anterior e peitoral maior na fase de alcance, e trapézio superior,

Study conducted at the Faculdade de Medicina of Universidade de São Paulo – Ribeirão Preto (SP), Brazil.
[1]Physiotherapy Course of the Faculdade de Medicina de Ribeirão Preto of Universidade de São Paulo (USP) – Ribeirão Preto (SP), Brazil.
[2]Graduate Program in Rehabilitation and Functional Performance of the Faculdade de Medicina de Ribeirão Preto of Universidade de São Paulo (USP) – Ribeirão Preto (SP), Brazil.

Corresponding address: Marisa de Cássia Registro Fonseca – Alberto Coselli Street, 445 – Ribeirão Preto (SP), Brazil – Zip Code: 14096-210 – E-mail: marisa@fmrp.usp.br –
Finance source: Fapesp Scholarship Protocol nº 2015/09728-2 – Conflict of interests: Nothing to declare – Presentation: Oct. 4th, 2016 – Accepted for publication: Dec. 19th, 2017 – Approved by the Research Ethics Committee of the Hospital das Clínicas da Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo (HCFMRP – USP) under protocol nº 777.193.

deltoide anterior e posterior na fase de liberação com a órtese. A cinemática mostrou aumento significativo na amplitude de movimento na abdução do ombro, flexão do cotovelo e pronação do antebraço na fase de deslocamento, e dos movimentos extensão do ombro e flexão do cotovelo na fase de liberação. Nossos achados sugerem que o uso da órtese estática do punho durante a execução de uma tarefa pode acarretar compensações, com predomínio da ativação dos músculos mais proximais do membro superior.
Descritores | Atividades Cotidianas; Eletromiografia; Fenômenos Biomecânicos; Extremidade Superior; Aparelhos Ortopédicos.

RESUMEN | Las ortesis son recursos terapéuticos indicados para proteger, corregir deformidades o auxiliar en ciertas funciones; sin embargo, su uso puede acarrear compensaciones proximales en el hombro. El objetivo de este estudio, entonces, es evaluar la influencia de la ortesis estática dorsal del puño, en 30° de extensión en la biomecánica del hombro y codo, en 25 voluntarios asintomáticos durante una tarea funcional. Los datos de la amplitud de movimiento y de la activación muscular han sido adquiridos de manera sincronizada y simultánea durante parte de la prueba funcional Elui, que simula la alimentación, dividida en alcance, desplazamiento y liberación, de un jarrón, en las condiciones sin y con ortesis. Para posibilitar la comparación entre los distintos individuos y músculos, los datos han sido analizados por la integral de la señal EMG de cada músculo y, para el análisis cinemático, han sido construidos sistemas de coordinadas de marcadores predefinidos. Las señales captadas han sido filtradas y procesadas por un software personalizado, y se ha utilizado la prueba t para muestras pareadas – software SPS®, p<0,05. Se ha visto un incremento significativo de la activación de los músculos deltoide anterior y pectoral más grande en la etapa de alcance, y trapecio superior, deltoide anterior y posterior en la etapa de liberación con la ortosis. La cinemática ha mostrado incremento significativo en la amplitud de movimiento en la abducción del hombro, flexión del codo y pronación del antebrazo en la etapa de desplazamiento, y de los movimientos extensión del hombro y flexión del codo en la etapa de liberación. En nuestros hallazgos se sugieren que el uso de la ortosis estática del puño durante la ejecución de una tarea puede acarrear compensaciones, con predominio de la activación de los músculos más proximales del miembro superior.
Palabras clave | Actividades Cotidianas; Electromiografía; Fenómenos Biomecánicos; Extremidad Superior; Aparatos Ortopédicos.

INTRODUCTION

The upper limb is an important segment for contact with the external environment, and the joint sensorimotor system and the peripheral sensory nerve fibers are essential for proper movement skills, enabling to perform the activities of daily living (ADLs)[1-3] such as grasping and handling of objects, feeding or dressing, directly depending on the proper stability of the wrist[4], mainly represented by the synergistic action of the extensor and flexor muscles of the wrist and fingers[5,6]. While performing a functional task with the fingers, the stabilizers of the wrist, elbow and shoulder help prevent compensatory movements and, therefore, are closely related[7].

Biomechanical studies using surface electromyography and kinematics have been used for objective and quantitative assessments of the upper limb[8,9]. Electromyography evaluates the muscular activity of the musculoskeletal system and the kinematic analysis evaluates the movement performed without taking its causes into account[10].

Orthoses are therapeutic devices to stabilize or immobilize, prevent or correct joint deformity, protect and assist the healing process or facilitate the functioning, and may have more than one purpose[11,12]. Orthoses are therapeutic resources and, as such, they should be prescribed considering anatomo-physiological principles related to the disease or dysfunction, after an individual evaluation in a rehabilitation process of the patient with a specific functional deficiency or pain issue, and they can be prefabricated or tailor made, produced from various thermoplastic materials of high or low temperature, involving a segment or one or more volar, dorsal or semi-circular joints[13,14]. Studies have shown that their use while performing functional tasks may lead to changes in the quality and pattern of movement across the upper limb, with compensations in terms of overload on the proximal muscles, when compared to the same movement without the device[15-18], increasing the risk of compensatory proximal lesions in the shoulder[19]. They have also shown that static wrist extension orthoses inhibit the activation of wrist extensors during finger gripping tasks, thus being indicated in specific pain cases[17]. However, no study has performed the simultaneous analysis of changes in joint kinematics and electromyographic activity in the upper limb in people with a wrist orthosis. Such findings can help rehabilitation professionals anticipate the effects and properly guide patients on the use of these devices while performing functional tasks. Then, this study aimed to analyze and compare the electromyographic activity and simultaneous kinematics of the shoulder and elbow while performing a functional task with and without a dorsal wrist extension static orthosis.

METHODOLOGY

This study was approved by the Research Ethics Committee of the Hospital das Clínicas da Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo, protocol nº 777.193. All study participants signed an informed consent form. The sample was calculated with GraphPad StatMate®, using the standard deviation of the values (μV) for the electromyographic activity of the extensor carpi radialis muscle while performing a gripping task. Data were obtained from a pilot study with 16 participants. The sample of 25 volunteers and 90% power was obtained.

Participants

Twenty-five healthy subjects, aged 18-35 years, male and female, with right hand dominance confirmed by Edinburgh inventory[20] were invited to participate in the study. Individuals with prior history of trauma or musculoskeletal dysfunction in the upper limbs and individuals diagnosed with cognitive impairment were not included.

Surface electromyography

A Delsys® (Trigno Wireless System) electromyography machine, set to the acquisition frequency of 2,000 Hz, was used to capture the activation of the studied muscles. The skin site where the sensors were placed had its hair removed and cleaned with 70% alcohol. The sensors were fixed in place by means of double-sided adhesive tapes supplied by the equipment manufacturer. The position of the sensors followed the recommendations of the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) project, so that the parallel bars of the sensors were perpendicular to the muscle fibers.

Kinematic analysis

For the kinematic analysis, a 3D image capture system (Nexus, Vicon Motion Systems Ltd®) comprised of eight infrared cameras that captured the movement by tracking seven passive reflective markers, which were fixed to the skin with double-sided adhesive tape (Figure 1). The positioning protocol of the markers was defined from a previous pilot study and the location of the markers on the trunk, shoulder and elbow was based on a protocol pre-established by the software. To ensure proper tracking of the markers while performing the movement, the cameras were arranged around the entire collection field. Then, all markers were tracked regardless of the utensils used to perform the dynamic functional test of the upper limb, or any change of limb position in the different planes of movement during the analyzed task.

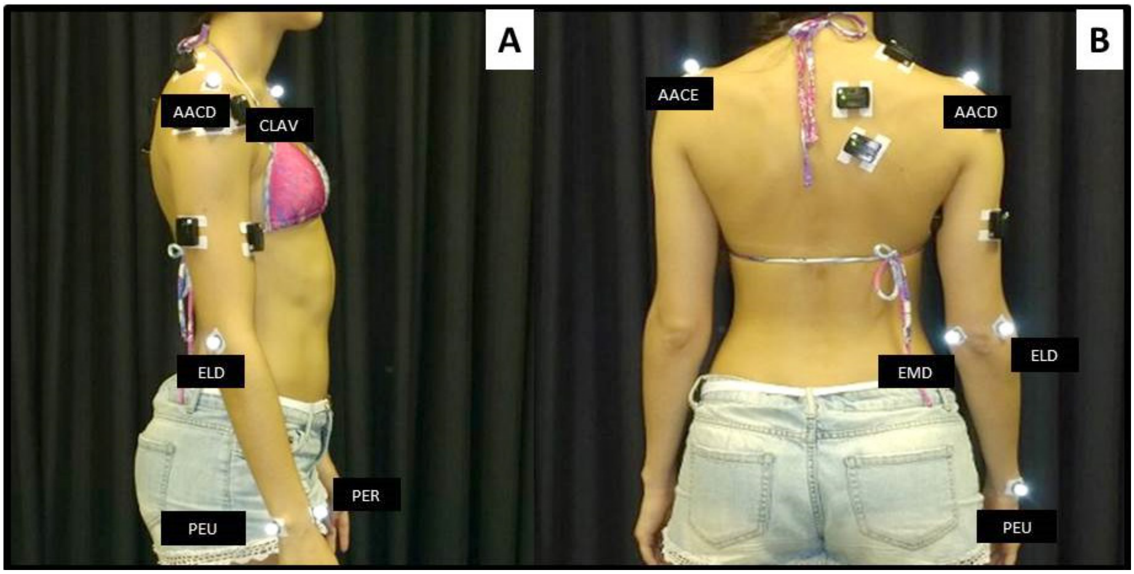


Figure 1. Position of reflective markers
A: side view; B: back view; CLAV: jugular notch of the sternum; AACE: Left acromioclavicular joint; AACD: Right acromioclavicular joint; ELD: Right lateral epicondyle; EMD: Right medial epicondyle; PEU: Midline of the forearm in the direction of the ulnar styloid process; PER: Midline of the forearm in the direction of the radial styloid process.

The kinematic analysis allowed to obtain the range of joint motion of flexion, extension, abduction and internal rotation of the shoulder, flexion, extension of the elbow and pronation and supination.

Signal processing

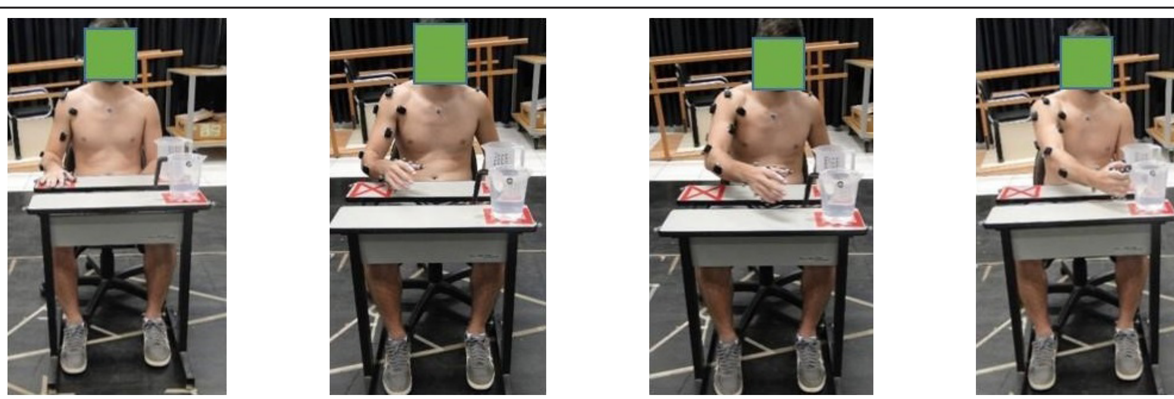
Trigno® Wireless is a system that allows the integration with Vicon Motion Capture System®, so that both electromyographic and kinematic data were acquired synchronously and simultaneously with Vicon Nexus Software®. After a pre-processing performed in the same software to adapt the exported data format, signal processing was performed offline in custom programs in Matlab® software (The MathWorks, Inc.).

The raw signal passed through a 4th-order bandpass Butterworth filter, with a cutoff frequency between 10 and 500 Hz. To obtain the linear envelopes (iEMG), the filtered signal was rectified and then filtered again using a 4th-order 15 Hz lowpass Butterworth filter. Then, iEMG corresponded to the mean integral of each muscle in the analysis window of interest, allowing subsequent comparisons[21,22].

In the kinematic analysis, data were filtered using a 4th-order lowpass Butterworth filter with a cut-off frequency of 5 Hz. Subsequently, local coordinate systems of the trunk, arm and forearm were built from seven predefined markers and following the recommendations of the International Society of Biomechanics[23]. Euler angles were used to obtain the joint angles. The movements were described from the distal segment in relation to the proximal segment following the Y-X-Y rotation sequence.

The task

A functional task was selected that simulates a feeding ADL that belongs to the Elui Functional Test for the Superior Member, or the Elui Test[24]. This is an easy-to-apply and reliable functional test that evaluates the functionality of the hand and upper limb, recording the time in seconds it takes to independently perform each of the seven tasks. The 'Pour Water' task was chosen because it involves gripping fingers with stabilization of the wrist extension, associated with the displacement of a load, which consisting of moving a jug with one liter of water from one place on the table and pouring its content into another jug away from it. To perform the task, a volunteer was placed sitting with his hand to be tested on the table at the indicated place, and the other hand remained all the time on the left thigh. After the 'go' command, he performed the following sequence of movements: pick up the plastic jug with water, go around the table, return, and pour the water into the other jug, and finally returning the empty jug to its original place (Figure 2). In addition to the markers on the volunteer, three markers were also placed on the first jar to track its displacement while performing the task, subdividing it into phases called reach, displacement, and release of the jug for data processing.

PHASE 1	REACH
IMAGES	
MAIN ACTIVITIES	- Load-free phase - Flexion, adduction and external rotation of the shoulder - Extension and supination of the elbow - Extension and ulnar deviation of the wrist - Grasp to hold the jug

(continues)

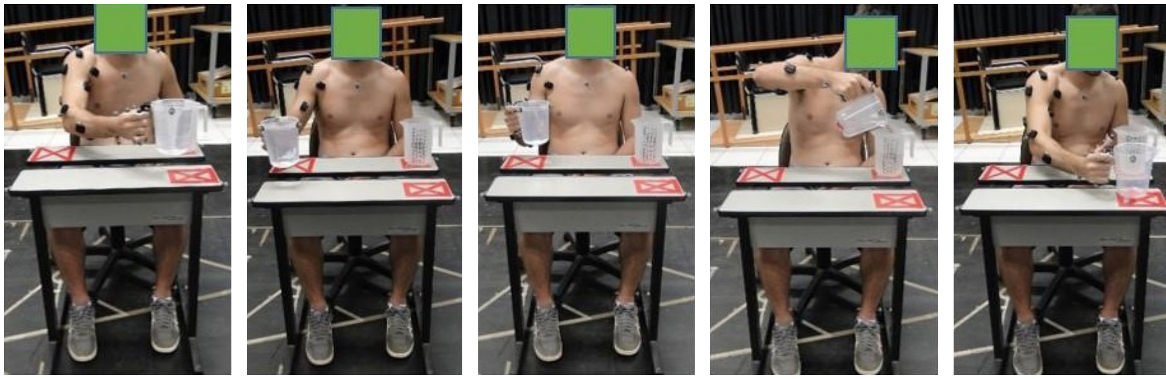
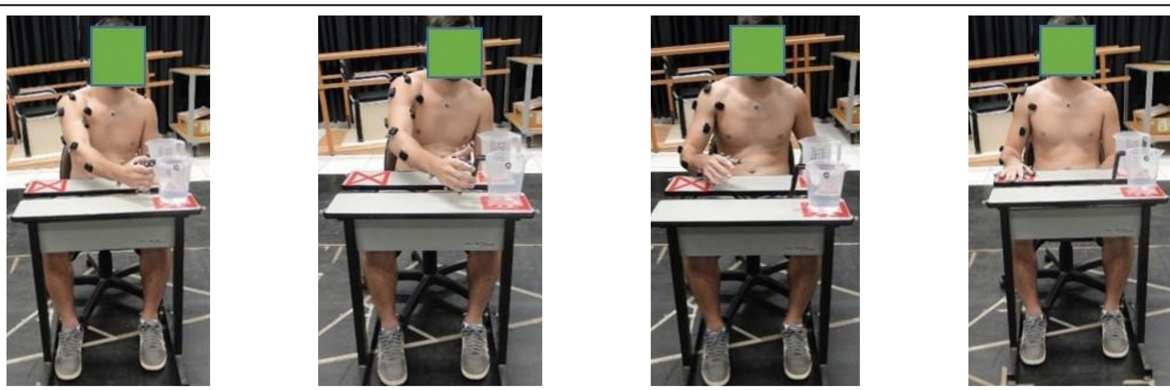
PHASE 2	DISPLACEMENT
IMAGES	
MAIN ACTIVITIES	- Phase with load support (1 liter, which is equivalent to 1 kg) - Adduction and extension of the shoulder (go around the table), followed by adduction and internal rotation (pour the water) - Flexion of the elbow (go around the table), pronation (pour the water) and extension with supination (return the jug) - Extension of the wrist and radial deviation remained - Pour the water into the empty jug
PHASE 3	**RELEASE**
IMAGES	
MAIN ACTIVITIES	- Load-free phase - Extension, adduction and internal rotation of the shoulder - Flexion and pronation of the elbow - Wrist at neutral position of flexion-extension and ulnar deviation - Return of the hand to start position

Figure 2. Start position and the phases of the task performed in the Elui test – 'Pour water': reach, displacement, and release

Orthosis

The dorsal wrist orthosis (Figure 3) was made of Taylor 3.2 mm low-temperature thermoplastic material for molding purposes and it was individually adapted to each volunteer by means of three adjustable Velcro straps, the first on the volar face of the hand and the other two on the forearm. The volunteers were evaluated while performing the functional task in two conditions in random order, with 2-minute interval: without the orthosis and with dorsal wrist orthosis at 30° extension. This angle was defined in previous electromyographic studies[25,26] as the one of the greatest muscular inhibition of wrist extensors, but allowing the grip of the fingers. The use of the orthosis on the dorsal side of the hand and forearm was selected to release the palmar face of the hand, for easy grasping of the fingers during the functional task.

Figure 3. Static orthosis at 30° extension of the dorsal wrist in thermoplastic material

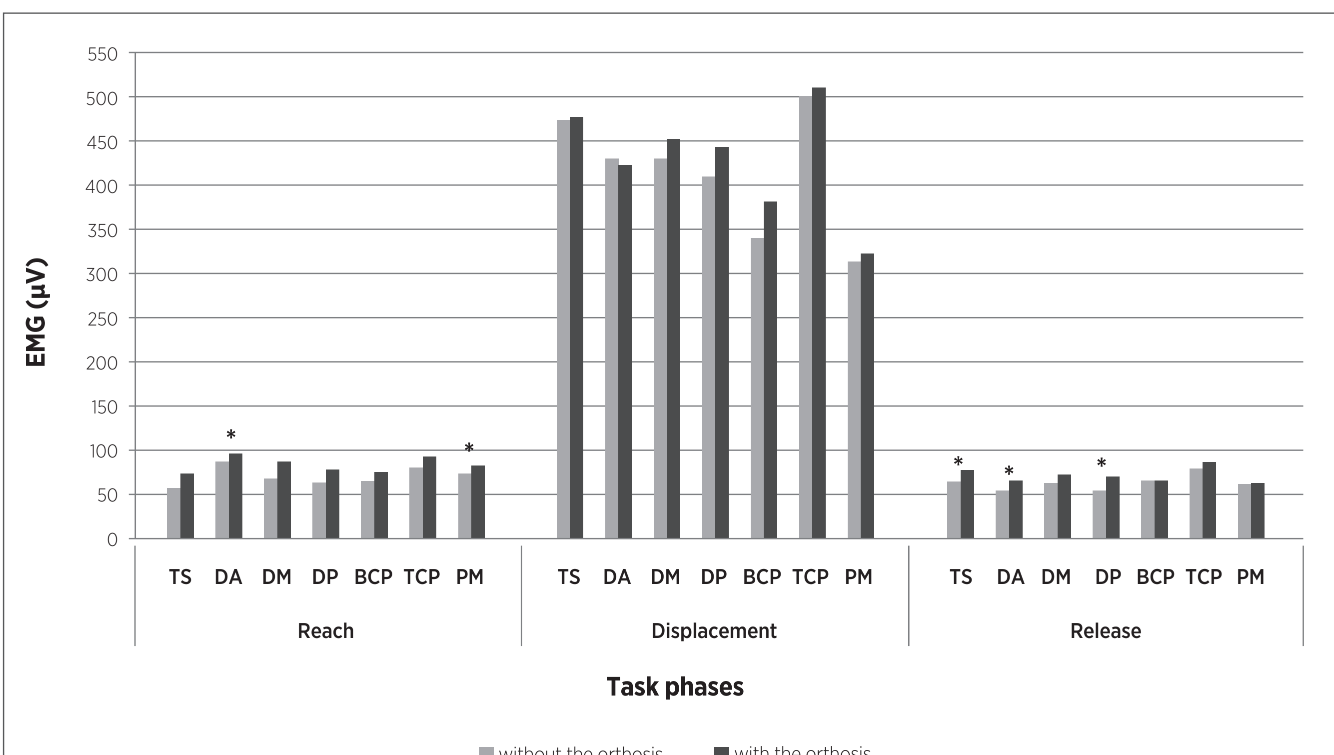
Data analysis

Data processing and graphic representations were developed offline using Matlab® software (The MathWorks, Natick, MA). Both muscle activity and range of motion were compared in different conditions. The kinematic analysis evaluated the average of the maximum values of each movement in each phase. The analysis of the electromyographic data used the mean value for the integral (iEMG) from the linear envelope of each muscle in each phase and each condition. The statistical analysis used the t-test for paired samples, after confirming data normality by the Shapiro-Wilk test, using the SPSS® software. The level of significance was $p < 0.05$.

RESULTS

The time to perform the 'Pour Water' task of the Elui Test[24] without the orthosis was on average 13.3±2.4 seconds. The reach phase corresponded to 11.31%, the displacement phase 77.43%, and the release phase 11.23% of the total cycle of the task. With the orthosis, the mean time to perform the task was 14.6±3.1 s; the reach phase corresponded to 11.95%, the displacement phase 77.15%, and the release phase 10.89 % of the total cycle of the task. No significant difference was observed between the conditions with and without the orthosis.

In the reach phase, a significant difference was observed in the mean value of the integral for the activation of the anterior deltoid muscle (AD) (87.93±17.22 μV) in the condition without the orthosis when compared to the AD (99.23±27.00 μV) with the orthosis, and the pectoralis major (PM) muscle (74.88±14.63 μV) without the orthosis when compared to the PM (85.27±25.44 μV) with the orthosis. During the analysis of the displacement phase, no significant difference was observed for any of the muscles analyzed. In the release phase, significant differences were observed for the activation of the upper trapezius (UT) (65.08±27.47 μV) without the orthosis, when compared to the same muscle with the orthosis UT (77.75±26.68 μV), AD (55.72±22.05 μV) without the orthosis when compared to the AD (66.85±21.21 μV) with the orthosis, and the posterior deltoid (PD) (55.89±19.01 μV) without the orthosis when compared to the PD (71.67±19.01 μV) with the orthosis (Graph 1).



Graph 1. Mean of the iEMG integral of each muscle, in each phase, in both conditions with and without the orthosis.
*Muscles with significant difference between the conditions (p≤0.05). Ts: Upper trapezius; DA: anterior deltoid; DM: medial deltoid; DP: posterior deltoid; BCP: biceps brachii; TCP: triceps brachii; PM: pectoralis major.

In the kinematic analysis, the average of the maximum values was obtained for each movement in each phase. During the reach phase, no significant difference was observed in the movements analyzed. However, in the displacement phase, significant differences were observed for shoulder abduction movements without the orthosis (00.12±10.90°) when compared to the use of the orthosis (-4.46±10.69°), flexion of the elbow without the orthosis (110.58±7.94°) when compared to the use of the orthosis (102.23±8.31°), and for elbow pronation without the orthosis (12.41±5.21°) when compared to the use of the orthosis (10.33±5.68°). In the release phase, a significant difference was observed for the movements of shoulder extension without the orthosis (2.79±16.68°) when compared to the use of the orthosis (8.45±14.51°), and elbow flexion without the orthosis (98.11±8.70°) when compared to the use of the orthosis (90.97±8.72°) (Table 1).

Table 1. Movements analyzed in each phase of the task

Phase	Reach				Displacement								Release			
Movement	FO		EC		AO*		RIO		FC*		PC*		EO*		FC*	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Without the orthosis	66,08	14,88	53,24	9,93	0,12	10,9	42,91	10,44	110,58	7,94	12,41	5,21	2,79	16,68	98,11	8,7
With the orthosis at 30°	65,09	14,62	52,05	33,85	-4,46	10,69	43,05	8,51	102,23	8,31	10,33	5,68	8,45	14,51	90,97	8,72

FO: shoulder flexion; EC: elbow extension; AO: shoulder abduction; RIO: internal rotation of the shoulder; FC: elbow flexion; PC: elbow pronation; EO: elbow extension. *Movements with statistically significant difference.

DISCUSSION

This study aimed to evaluate the influence of static wrist orthosis at a 30° extension on the biomechanics of the shoulder and elbow in asymptomatic individuals while performing a functional task. For this study, we considered the hypothesis that the standardized static wrist orthosis could alter the activation of the muscles and the range of motion of the upper limb. The selection of this orthosis was based on the studies conducted by Jansen et al.[25] and Marcolino et al.[26], who analyzed the influence of these orthoses at several wrist angles through electromyography of the wrist extensor muscles and observed reduced extensor muscle activation with orthoses at 30° extension, while performing a functional task of isometric grip.

Distal stabilization of the upper limb by means of an external device promotes a rearrangement of the entire proximal muscle and joint chain, so that the overall function is not impaired, with loss of fine and more specific movements. According to the electromyographic data obtained in this study, during the reach phase there was a greater interaction of the anterior deltoid and pectoralis major muscles, which would be explained by a probable proximal muscle compensation due to the distal restriction on the wrist caused by the orthosis while performing the task functional. In contrast, Ricci et al.[22] did not observe a greater activation of the pectoralis major during the same phase, when the patterns of movement and muscular activation were analyzed while performing the same functional task, but without orthoses.

The displacement phase was characterized mainly by the transport of the jar with water and the displacement of the arm in the space. A relation of similarity of the muscular activation pattern can be observed in the displacement phase in the two conditions (with and without the orthosis), since there was no significant difference of activation in any of the muscles in that phase when comparing both conditions. It is due to the fact that during this phase, the wrist stabilization occurs not only because of the presence of the orthosis, but also because of the synergism of the forearm musculature required for any transport activity, allowing an isometric and stable contraction[27]. Therefore, the displacement phase is less influenced by the presence or absence of the orthosis, and it is a probable justification for the data obtained.

The release phase predominantly comprises movements supported by gravity; therefore, they require less muscular effort. The result obtained in the release phase shows that the co-contraction of the anterior deltoid and posterior deltoid muscles keeps the proximal stability of the limb to the detriment of wrist immobilization. Yoo et al.[28] obtained similar results as they also demonstrated a significant increase in upper trapezius activation while performing an assembly task that required shoulder movement in space, when comparing the condition with and without the orthosis. Another study[29] also demonstrated that during a manufacturing task in which volunteers had to move objects and place them into a box, there was a significant increase in the activation of the upper trapezius, anterior deltoid, and posterior deltoid. With an electromyographic analysis, Ferrigno et al.[30] reported that the use of a static wrist orthotics during a typing and computer mouse handling task also influenced the higher recruitment of the upper trapezius muscle, in agreement with the findings of this study.

During the reach phase, the main movements observed were shoulder flexion and elbow extension, which did not present significant difference when comparing the two conditions. Our findings differ from another study involving the use of a static wrist orthosis for the comparison of the effect of immobilization versus non immobilization when performing the movements of flexion, abduction, and shoulder rotation while feeding, in which a significant difference was found for the flexion and abduction movements, leading to a greater muscular activation of the shoulder with the orthosis in the feeding movement[31]. A hypothesis for this difference in results may be the type of task selected, since the functional task of carrying a jar is a gross motor activity when compared to the feeding movement.

Shu and Mirka[32] suggested, in a kinematic study that used an occupational task, a significant increase in shoulder abduction and trunk posture when the task was performed with the orthosis in the neutral position of the wrist when compared to the task without the orthosis. In this study, in the displacement phase, the presence of abduction movements and internal rotation of the shoulder, flexion and pronation of the elbow were observed. The negative value obtained in our results of this movement confirmed that during the displacement phase no abduction of the shoulder was observed in relation to its starting point. The use of the wrist orthosis limited mainly the movements originated at the proximal joints of immobilization. Therefore, due to wrist immobilization with the orthosis, significant differences were also observed in elbow flexion and pronation movements, since this task required a greater movement of excursion.

The predominant movements in the release phase were shoulder extension and elbow flexion, which can be considered the opposite pattern of the reach phase. A significant difference was observed for these movements when performed with and without the wrist orthosis, with great variability in the movement pattern among the volunteers.

Chang and Jung[33] proposed that the use of volar wrist orthosis when performing skilled activities significantly reduced the generation of force and the time to perform the analyzed activities. Therefore, the authors explain the importance of the theoretical knowledge and a good evaluation when prescribing an orthosis.

The study limitations include the use of volunteers without injury in the upper limb, when simulating activities without prior training. Further studies are required to analyze biomechanical changes in clinical situations and while performing different functional tasks.

CONCLUSION

This study demonstrated that the use of a wrist orthosis at 30° extension altered the biomechanics of the shoulder and elbow when performing the selected task, with emphasis on greater muscular activation of the proximal muscles of the upper limb. A proper evaluation of the patient is required to prescribe the use of an orthosis, due to the effects that this device can produce in terms of biomechanical compensations while performing a task.

ACKNOWLEDGEMENT

The authors would like to thank the Fundação de Amparo à Pesquisa do Estado de São Paulo for the equipment and scholarship provided to support this study.

REFERENCES

1. Hoozemans MJM, Dieen JH. Prediction of handgrip forces using surface EMG of forearm muscles. J Electromyogr Kinesiol. 2005;15(4):358-66. doi: 10.1016/j.jelekin.2004.09.001
2. Fonseca MCR, Ferreira AM, Hussein AM. Sistema sensório-motor articular: revisão da literatura. Fisioter Pesqui. 2007;14(3):82-90.
3. Finneran A, O'Sullivan L. Effects of grip type and wrist posture on forearm EMG activity, endurance time and movement accuracy. Int J Ind Ergon. 2013;43(1):91-9. doi: 10.1016/j.ergon.2012.11.012
4. Weiss AC, Hastings H. Upper extremity function after wrist arthrodesis. J Hand Surg. 1995;20(5):813-7. doi: 10.1016/S0363-5023(05)80437-X
5. Kapandji AI. A mão. In: Kapandji AI. Fisiologia articular: esquemas comentados de mecânica humana. 5ª ed. São Paulo: Panamericana; 2000. p. 174-298.

6. Ferreira AM, Fonseca MCR, Tanaka DM, Barbosa RI, Marcolino AM, Elui VMC, et al. Should we think about wrist extensor after flexor tendon repair? SAGE Open Med. 2013;1:1-6. doi: 10.1177/2050312113494974

7. Safaee-Rad R, Shwedy E, Quanbury AO, Cooper JE. Normal functional range of motion of the upper limb joints during performance of three feeding tasks. Arch Phys Med Rehabil. 1990;71(7):505-9.

8. Basmajian JV, de Luca CJ. Muscle alive: their function revealed by electromyography. 5ª ed. Baltimore: Williams & Wilkins; 1985.

9. Cram J; Kasman G, Holtz J. Introduction to surface electromyography. Gaithersburg: Aspen; 1998.

10. Kamen G. Biomechanics analysis techniques: a primer. In: Robertson DGE, Caldwell GE, Hamill J, Kamen G. Research methods in biomechanics. 2ª ed. Champaign: Human Kinetics; 2014. p. 1-5.

11. McKee P, Morgan L. Orthotics in rehabilitation: splinting the hand and body. Philadelphia: F. A. Davis Company; 1998. Chapter 1, Objectives, design and terminology; p. 1-18.

12. Marcolino AM, Fonseca MCR, Barbosa RI, Elui VMC, Luzo CM. Órteses da mão e membro superior. In: Fonseca MCR, Marcolino AM, Barbosa RI, Elui VMC. Órteses & próteses: indicação e tratamento. Rio de Janeiro: Águia Dourada; 2015. p. 147-72.

13. Araujo PMP. Avaliação funcional. In: Freitas PP, editor. Reabilitação da mão. São Paulo: Atheneu; 2006. Capítulo 3.

14. McKee P. Foundations of orthotic intervention. In: Skirven TM, Osterman AL, Fedorczyk J, Amadio PC. Rehabilitation of the hand and upper extremity. 6ª ed. Amsterdam: Elsevier; 2011. Chapter 122; p. 1565-80.

15. Fess EE; Gettle KS; Philips CA; Janson JR. Hand and upper extremity splinting: principles and methods. 3rd ed. Amsterdam: Elsevier; 2005.

16. King S, Thomas JJ, Rice MS. The immediate and short-term effects of a wrist extension orthosis on upper-extremity kinematics and range of shoulder motion. Am J Occup Ther. 2003;57:517-24. doi: 10.5014/ajot.57.5.517

17. van Petten AMVN, Avila AF. Efeito do uso de órtese de punho na ativação da musculatura flexora e extensora do punho. Rev Bras Ortop. 2010;45(1):72-8. doi: 10.1590/S0102-36162010000100013

18. Bulthaup S, Cipriani DJ, Thomas JJ. An electromyography study of wrist extension orthoses and upper-extremity function. Am J Occup Ther. 1999;53(15):434-40. doi: 10.5014/ajot.53.5.434

19. Perez-Balke G, Buchholz B. Role of wrist immobilization in the work environment: ergonomics and carpal tunnel syndrome. Work. 1994;4(3):187-94. doi: 10.3233/wor-1994-4306

20. Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia. 1971;9(1):97-113. doi: 10.1016/0028-3932(71)90067-4

21. Ervilha UF, Duarte M, Amadio AC. Estudo sobre procedimentos de normalização do sinal eletromiográfico durante o movimento humano. Rev Bras Fisioter. 1998;3(1):15-20.

22. Ricci FP, Santiago PR, Zampar AC, Pinola LN, Fonseca MCR. Upper extremity coordination strategies depending on task demand during a basic daily activity. Gait Posture. 2015;42(4):472-8. doi: 10.1016/j.gaitpost.2015.07.061

23. Wu G, van der Helm FCT, Veeger HEJ, Makhsous M, van Roy P, Anglin C, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion: part II: shoulder, elbow, wrist and hand. J Biomech. 2005;38(5):981-92. doi: 10.1016/j.jbiomech.2004.05.042

24. Elui VMC, Goia DN, Ricci FPFM, Fonseca MCR. Confiabilidade de um teste funcional de desempenho do membro superior: teste Elui. Acta Fisiátr. 2014;21(3):101-6. doi: 10.5935/0104-7795.20140021

25. Jansen CW, Olson SL, Hasson SM. The effect of use of a wrist orthosis during functional activities on surface electromyography of the wrist extensors in normal subjects. J Hand Ther. 1997;10(4):283-9. doi: 10.1016/S0894-1130(97)80043-9

26. Marcolino AM, Fonseca MCR, Colombari F, Rodrigues EKS, Tamanini G, Barbosa RI. Influence of volar and dorsal static orthoses in different wrist positions on muscle activation and grip strength in healthy subjects. Hand Ther. 2014;19(4):114-25. doi: 10.1177/1758998314563722

27. Souza VK, Claudino AF, Kuriki HU, Marcolino AM, Fonseca MCR, Barbosa RI. Fadiga dos músculos extensores do punho diminui a força de preensão palmar. Fisioter Pesqui. 2017;24(1):100-6. doi: 10.1590/1809-2950/17328524012017

28. Yoo IG, Jung MY, Jeon HS, Lee J. Effects of wrist-extension orthosis on shoulder and scapular muscle activities during simulated assembly tasks. Ind Health. 2010;48(1):108-14. doi: 10.2486/indhealth.48.108

29. Mell AG, Friedman MA, Hughes RE, Carpenter JE. Shoulder muscle activity increases with wrist splint use during a simulated upper-extremity work task. Am J Occup Ther. 2006;60:320-26. doi: 10.5014/ajot.60.3.320

30. Ferrigno ISVF, Cliquet Junior A, Magna LA, Zoppi Filho A. Electromyography of the upper limbs during computer work: a comparison of 2 wrist orthoses in healthy adults. Arch Phys Med Rehabil. 2009;90(7):1152-8. doi: 10.1016/j.apmr.2009.01.016

31. May-Lisowski TL, King PM. Effect of wearing a static wrist orthosis on shoulder movement during feeding. Am J Occup Ther. 2008;62:438-45. doi: 10.5014/ajot.62.4.438

32. Shu Y; Mirka G A. A laboratory study of the effects of wrist splint orthoses on forearm muscle activity and upper extremity posture. Hum Factors. 2006;48(3):499-510. doi: 10.1518/001872006778606859

33. Chang M, Jung NH. Comparison of task performance, hand power, and dexterity with and without a cock-up splint. J Phys Ther Sci. 2013;25(11):1429-31. doi: 10.1589/jpts.25.1429