Journal of Orthopaedic & Sports Physical Therapy
Official Publication of the Orthopaedic and Sports Physical Therapy Sections of the American Physical Therapy Association

The Application of an External Wrist Extension Force Reduces Electromyographic Activity of Wrist Extensor Muscles During Gripping

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Study Design: Experimental repeated-measures study.
Objective: To investigate the effect of different extension forces applied to the palm of the hand on electromyographic (EMG) activity of the wrist extensor muscles during hand gripping.
Background: Lateral epicondylitis is usually caused by repetitive wrist extension that leads to an overuse injury. The current theory is that the process of lateral epicondylitis begins with an overuse injury that leads to microtearing of the extensor carpi radialis brevis muscle and occasionally the extensor digitorum communis muscle. Use of an external wrist extension force might reduce muscle activity during gripping.
Methods: Muscle activity was measured using surface EMG while subjects gripped at an intensity of 10%, 20%, and 30% of the maximum voluntary contraction force without, and with, an applied external wrist extension force of 1%, 2%, and 3% of maximum voluntary contraction.
Results: Applying an extension force to the palm of the hand reduced EMG activity of the extensor muscles at the same strength generation during hand gripping. The muscles with the most significant reduction in EMG level, the extensor carpi radialis brevis and extensor digitorum communis, are those muscles that are most often involved with lateral epicondylitis.
Conclusions: This study shows that an external extension force reduces EMG activity of the wrist extensor muscles during gripping in healthy volunteers. As the extension force increased, a greater reduction in muscle activity was noted. *J Orthop Sports Phys Ther 2004;34:228-234.*

Key Words: *dynamometer, elbow, forearm, isometric force, lateral epicondylitis*

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Lateral epicondylitis was first referred to as ''writers cramp'' in 1873 and has been described as a pathological condition of the common wrist extensor origin that causes pain during wrist extension.[12] The incidence of lateral epicondylitis is approximately between 4 and 7 per 1000 patients per year, with an incidence of 1% to 3% in the overall population.[15] In approximately 10% of cases the complaint will result in sick leave for a period of 11 weeks on the average.[15] Untreated, the complaint is estimated to last from 6 months to 2 years.[15,17] Lateral epicondylitis is usually caused by repetitive wrist extension that leads to an overuse injury. Although the pathophysiology is not yet fully understood, primary pathological changes have been observed during surgery of the elbow in the proximal musculotendinous origin of the extensor carpi radialis brevis (ECRB) muscle.[11] The current theory is that the process of lateral epicondylitis starts with an overuse injury that leads to microtearing of the ECRB and occasionally the extensor digitorum communis (EDC) muscle.[6]

Numerous nonsurgical intervention approaches have been described for the treatment of lateral epicondylitis.[3,11,13] One of these intervention approaches is the use of circumferential braces applied around the proximal forearm region. These braces are designed to reduce load on the wrist extensor muscles during functional activities. A recent review article did not show any clear advantages in pain, grip strength, and subjective outcome measures of the use of this type of braces in patients with lateral epicondylitis.[15] Jansen et al[5] demonstrated that a volar and a dorsal wrist orthosis did not result in a significant reduction in extensor muscle activity using surface electromyography (EMG) during 3 lifting tasks. However, the same study demonstrated that a semicircular wrist orthosis did reduce the EMG activity of the ECRB muscle during similar lifting tasks.[5] Newport and Shukla[8] investigated the effect of dynamic extensor splinting on surface EMG activity of the EDC muscle in healthy volunteers. A dynamic extensor splint allows the wrist to move through its range of motion while applying a wrist extension force on the hand. This should reduce the EMG activity of the extensor muscles during functional activity. Indeed, during active flexion and passive extension (ie, basic position while wearing the brace), the EDC showed no EMG activity in 18 out of the 19 subjects wearing the splint, indicating that there was no stress on the tendon.

Therefore, dynamic splinting may be useful for reducing extensor muscle activity during functional activities, which could be beneficial in the treatment of patients with lateral epicondylitis. To assess the effect of a dynamic extensor splint, it is necessary to investigate whether or not an extension force applied to the palm of the hand reduces the activity of the wrist extensor muscles during hand gripping.

Gripping, which activates the flexor muscles, creates a flexion moment about the wrist joint and as a result the extensor muscles are coactivated, producing an extension moment that stabilizes the wrist joint.[12] Snijders et al[14] showed, using EMG, that the ECRB, EDC, and extensor carpi radialis longus (ECRL) muscles are all activated during gripping.

The purpose of the present study, therefore, is to investigate the effect of an extension force applied to the palm of the hand on EMG activity of the wrist extensor muscles during hand gripping. Because of limitations in EMG recording during dynamic movement, an extension force was applied at different wrist angles. The effect of 3 different (functional) wrist angles, 3 different gripping intensities (representative of daily life activities), and 3 different passive wrist extension forces on changes in EMG activity were assessed.

We hypothesize that applying an extension force to the palm of the hand will reduce the EMG activity of the extensor muscles during hand gripping, as it is likely that the production of the extension moment is partially provided by the externally applied force.

METHODS

Subjects

This study included 20 healthy volunteers who gave their written informed consent before testing. Subjects who had neurological or rheumatic disorders or a history of muscular, neural, or bone injuries to the lower arm or wrist were excluded from this study. Biometrical characteristics of the subjects are shown in Table 1. The study was approved by the Ethical Committee of Human Research (CMO) of Arnhem and Nijmegen.

Study Protocol

Subjects were asked to not perform any strenuous exercise on the day of the study. Surface EMG electrodes (Biomedical Engineering Department, University of Nijmegen, The Netherlands) with a diameter of 5 mm were placed, with a 2-cm interelectrode distance, over the ECRB, EDC, and ECRL. Electrodes were applied on the right forearm after shaving the area and properly cleaning the skin. Positions were determined using palpation while the subject was alternatively activating and deactivating the extensor muscles. Electrodes were placed on the thickest part of the muscle belly in accordance with Merletti et al.[7] Subjects were seated and asked to place their right forearm on a plate with their elbow between 60° and 90° of flexion, the forearm in neutral position between pronation and supination, and the wrist in neutral radial/ulnar deviation. The position of the arm was examined by the assessor during each measurement. The forearm was fixated at the distal end with a strap to a vertical bar attached to the plate. Proximally, the forearm was held against a vertical plate on the medial side of the forearm (Figure). Grip force was assessed using a

TABLE 1. Subjects characteristics (n = 20).

Variables	Statistics
Age (y)	27.0 ± 9.2*
Mass (kg)	70.6 ± 13.2*
Height (m)	1.76 ± 0.11*
Male/female	10/10†
Right handed/left handed	16/4†

* Mean ± SD
† n

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hand grip dynamometer manufactured at the University of Nijmegen (Biomedical Engineering Department, University of Nijmegen, The Netherlands).

First, the maximum voluntary contraction (MVC) force for grip strength was measured 3 times, for a duration of 2 to 3 seconds, with the wrist in 15° of extension. A resting period of 1 minute was given between measurements. If the achieved MVC levels differed by more than 10% from each other, an extra trial was collected. The trial with the highest grip strength value was used as the MVC. Next, subjects were asked to grip at approximately 10%, 20%, and 30% of their grip MVC force for 5 seconds using a monitor that displayed the grip force as visual feedback. These levels of grip MVC were chosen because they represent levels of effort performed during most daily activities.[2,10]

After a 20-second rest period, a strap used to apply the wrist extension force, was placed over the palm of the subject's hand (Figure). The extension force was applied by weights, pulling via a cable at an angle of 90° with the hand. Three different extension forces were used: 1%, 2%, and 3% of the individual grip MVC. This was approximately 10, 20, and 30 N for men and 5, 10, and 15 N for women. These forces also correspond to values that could be used in future commercial braces. Subjects were asked again to grip at 10%, 20%, and 30% of their grip MVC for 5 seconds, with their wrist still in 15° of extension, as a force equal to 1% of their MVC was pulling the

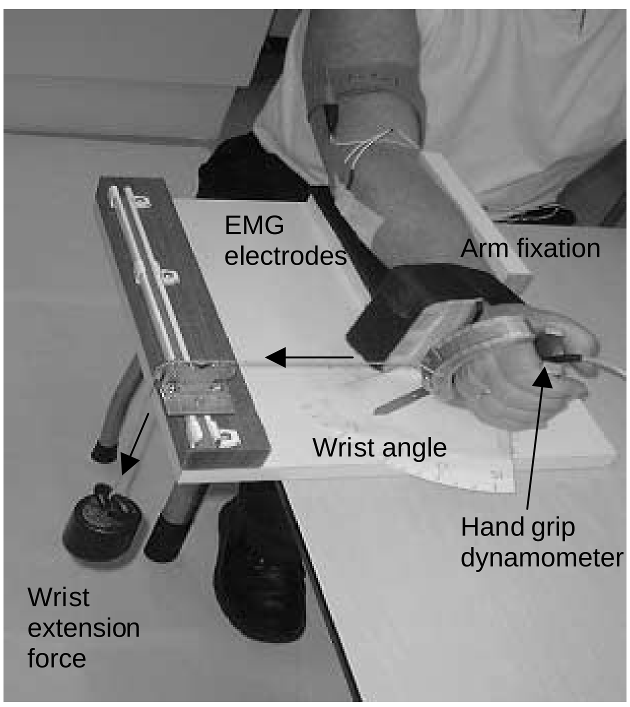

FIGURE. The angle of the wrist can be securely positioned and reproduced. The arm is fixated at the wrist. The wrist extension force is applied by a weight, which is attached via a cable to a strap around the palm of the hand at an angle of 90° (by adjusting the position on the rails).

wrist in extension. Testing was then repeated with the extension force set at 2% and 3% of the grip MVC. The total procedure was repeated twice thereafter; once with the wrist in 30° of extension and once with the wrist in neutral (0°) position. The surface EMG signals and the grip force were recorded during every measurement. For each gripping intensity and wrist angle, 1 trial was collected and all subjects were tested following the exact sequence just described.

Five subjects were measured twice to determine the reproducibility of the whole test procedure. One person conducted all EMG electrode applications, assessments, and analyses to exclude intertester variability.

EMG Data

Bipolar surface EMG electrodes were connected to an amplifier with a first-order passive filter with a low-pass cutoff frequency of 250 Hz and a high-pass cutoff frequency of 10 Hz (Biomedical Engineering Department, University of Nijmegen, The Netherlands). Data were recorded on a computer using a Keithley Dash1602 ADC board and Poly software (Inspector Research Systems BV, Gouda, The Netherlands). MATLAB Version 6.1 software (Math Works, Natick, MA) was used to perform root-mean-square (RMS) processing of the raw EMG signal.[7] During every 5-second measurement, a 1-second RMS value (the 1 second in which the produced grip strength values were similar for the trials with and without an extension force) was used for data analysis because the 1-second duration provides an accurate representation of the entire 5-second duration (pilot study, data not shown).

Data Analysis

EMG data results are presented as the percentage value of gripping with the wrist extension force compared to gripping without the extension force for the same wrist angle and percentage gripping force ([RMS with extension force/RMS without extension force] × 100%), with 95% confidence intervals (CIs). If 100% (which represents muscle activity without extension force) is outside the range of the 95% CI, changes are considered significantly different. We calculated 81 CIs from the same group of 20 subjects, possibly inflating the type I error for this analysis.

Reproducibility of the testing procedure was calculated as the coefficient of variation in 5 subjects and a correlation coefficient was calculated for separate measurements.

Furthermore, to evaluate differences between muscles, the effects of the wrist angle, the percentage of MVC, and the degree of extension force on EMG activity, we applied a repeated-measures ANOVA. The variables for the repeated-measures ANOVA was muscle with 3 levels (ECRB, EDC, and ECRL), the wrist angle with 3 levels (0°, 15°, and 30°), the percentage of MVC with 3 levels (10%, 20%, and 30% MVC), and the extension force with 3 levels (1%, 2%, and 3% MVC). Only for significant effects post hoc *t* tests were performed with a Bonferroni correction for multiple testing. Effects and differences were considered significant at $P<.05$.

RESULTS

The repeated-measures ANOVA revealed a significant effect of the extension force on EMG activity ($P<.001$), where the EMG activity decreased with increasing extension force. The wrist angle had a significant effect on EMG activity ($P = .001$), where the reduction in EMG activity as a result of the extension force was the largest at 15° extension, but did not differ significantly between 0° and 30°. Although no significant muscle effect was found, the ECRB and EDC showed the largest reductions in EMG activity when an extension force was applied. Also, there were complex interactions, such as extension angle by %MVC by extension force ($P = .027$; 3-way interaction) and extension angle by %MVC by extension force by muscle ($P = .01$; 4-way interaction). Because the data were normalized to the control condition, the ANOVA did not evaluate differences between the control condition (ie, the condition without extension force) and other conditions, which can be detected by using the 95% CIs.

Tables 2, 3, and 4 show the amount of RMS EMG activity of each individual muscle while gripping with a wrist extension force applied to the hand, as a percentage of the EMG activity when gripping without the extension force. In these tables, data for the individual muscles are presented using 95% CIs to detect the differences between each experimental condition and the control condition corresponding to the same wrist angle and %MVC. Significant effect of the extension force is noted when 100% is not included within the CI.

ECRB

At all wrist angles, the RMS EMG values at 10% of the gripping MVC were significantly lower at all extension force values compared to gripping without the extension force. RMS EMG values were significantly reduced with a 3% extension force, compared to without, for all wrist angles and gripping intensities. At 20% and 30% of the gripping MVC, the EMG RMS values were lower, with a 2% extension force in the 15° wrist angle only (Table 2).

EDC

At 1% and 2% extension force, the RMS EMG values during gripping at a 15° wrist angle were significantly reduced at all percentage gripping MVC values. Reduction in EMG RMS values were also detected with 2% extension force for the 30° wrist angle and 30% gripping MVC condition, and the 0° wrist angle at 10% and 20% gripping MVC conditions. At a 3% extension force significantly lower EMG RMS values were found during gripping at a 15° wrist angle at all grip strength intensities, gripping at a 30° wrist angle at 10% and 20% gripping MVC, and gripping with a 0° wrist angle at 10% gripping MVC (Table 3).

ECRL

A wrist extension force corresponding to 1% of the maximum voluntary gripping force did not significantly affect EMG RMS values for the ECRL. At 2% extension force, RMS values were significantly reduced when gripping with a 30° wrist angle at 10% and 20% of gripping MVC. At 3% extension force, only gripping at a 15° wrist angle at 20% and 30% gripping MVC, and at a 30° wrist angle at 10% and 20% gripping MVC, revealed significantly lower EMG RMS values (Table 4).

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TABLE 2. Percentage (mean and 95% confidence interval) of electromyographic activity of the extensor carpi radialis brevis during gripping with a wrist extension force applied to the palmar aspect of the hand, in comparison to the same test without extension force. As indicated by asterixes, there were lower electromyographic root-mean-square values during testing with the application of the extension force as compared to a trial performed at the same wrist angle and grip strength (as a percentage of the grip strength obtained during maximal voluntary contraction [%MVC]) without the extension force.

Wrist Extension Angle	Grip Strength (%MVC)	Extension Force 1%	Extension Force 2%	Extension Force 3%
0°	10	86.7 (78.0-95.5)*	78.0 (69.2-86.9)*	55.6 (45.2-66.0)*
	20	102.4 (93.4-111.4)	95.5 (89.6-101.4)	79.3 (68.4-90.2)*
	30	108.4 (99.7-117.1)	102.3 (94.2-110.4)	87.4 (78.2-96.5)*
15°	10	90.3 (81.5-99.2)*	69.9 (62.5-77.2)*	50.3 (42.6-58.0)*
	20	94.9 (87.5-102.3)	84.9 (77.9-91.9)*	64.0 (54.5-73.6)*
	30	98.5 (90.9-106.0)	88.6 (81.2-96.0)*	74.3 (66.9-81.6)*
30°	10	92.8 (86.0-99.7)*	79.1 (71.9-86.2)*	51.6 (43.1-60.2)*
	20	99.5 (90.9-108.1)	94.7 (84.2-105.2)	75.4 (66.3-84.5)*
	30	105.0 (94.4-115.5)	96.5 (87.7-105.4)	85.5 (77.5-93.5)*

* Significant differences: present when the 95% confidence interval does not include 100% (the value of the control condition).

TABLE 3. Percentage (mean and 95% confidence interval) of electromyographic activity of the extensor digitorum communis during gripping with a wrist extension force applied to the palmar aspect of the hand, in comparison to the same test without extension force. As indicated by asterixes, there were lower electromyographic root-mean-square values during testing with the application of the extension force as compared to a trial performed at the same wrist angle and grip strength (as a percentage of the grip strength obtained during maximal voluntary contraction [%MVC]) without the extension force.

		Extension Force		
Wrist Extension Angle	Grip Strength (%MVC)	1%	2%	3%
0°	10	82.0 (66.9-97.1)*	74.8 (63.0-86.7)*	68.1 (46.4-89.9)*
	20	88.1 (74.0-102.1)	83.1 (69.9-96.3)*	86.4 (58.2-114.5)
	30	108.9 (92.6-125.1)	99.4 (85.4-113.5)	87.1 (71.0-103.2)
15°	10	79.4 (64.7-94.2)*	72.6 (53.9-91.3)*	64.1 (45.5-82.8)*
	20	81.6 (67.8-95.4)*	80.5 (65.6-95.4)*	60.0 (50.7-69.2)*
	30	77.7 (66.9-88.5)*	83.3 (69.5-97.0)*	64.1 (55.3-72.9)*
30°	10	103.5 (67.0-140.0)	86.3 (56.3-116.3)	66.5 (43.8-89.1)*
	20	92.6 (66.1-119.1)	91.8 (72.6-111.0)	72.0 (49.9-94.1)*
	30	95.7 (84.5-107.0)	88.2 (77.3-99.1)*	83.0 (65.9-100.2)

* Significant differences: present when the 95% confidence interval does not include 100% (the value of the control condition).

TABLE 4. Percentage (mean and 95% confidence interval) of electromyographic activity of the extensor carpi radialis longus during gripping with a wrist extension force applied to the palmar aspect of the hand, in comparison to the same test without extension force. As indicated by asterixes, there were lower electromyographic root-mean-square values during testing with the application of the extension force as compared to a trial performed at the same wrist angle and grip strength (as a percentage of the grip strength obtained during maximal voluntary contraction [%MVC]) without the extension force.

		Extension Force		
Wrist Extension Angle	Grip Strength (%MVC)	1%	2%	3%
0°	10	111.1 (94.0-128.1)	111.3 (83.2-139.4)	88.7 (63.5-114.0)
	20	96.3 (83.3-109.3)	94.9 (81.6-108.3)	85.0 (67.5-102.6)
	30	111.8 (96.1-127.5)	99.6 (87.5-111.7)	88.2 (75.4-100.9)
15°	10	114.7 (97.4-131.9)	104.6 (71.0-138.3)	82.0 (60.1-104.0)
	20	106.7 (92.2-121.3)	94.4 (75.4-113.5)	79.1 (60.1-98.1)*
	30	102.8 (87.3-118.4)	91.3 (79.1-103.6)	74.0 (61.8-86.3)*
30°	10	96.3 (79.5-113.0)	86.1 (73.3-99.0)*	72.4 (45.7-99.1)*
	20	93.3 (82.5-104.1)	80.2 (68.9-91.5)*	69.8 (56.5-83.1)*
	30	102.8 (91.0-114.6)	96.0 (83.9-108.1)	86.8 (68.5-105.2)

* Significant differences: present when the 95% confidence interval does not include 100% (the value of the control condition).

Grip Strength

To verify that there were no differences in grip strength between gripping without and with an extension force, descriptive data are presented in Table 5. All values were within 2.5 N, indicating that grip strength remained the same across the different test conditions.

Reproducibility

The coefficient of variation in RMS EMG was 10.5% in 5 subjects, who were measured twice, indicating that the measurements were reproducible. The correlation coefficients (r) for the 2 measurements of RMS EMG for the ECRB, ECRL, and EDC were 0.84, 0.73, and 0.66, respectively.

DISCUSSION

The present study clearly shows that applying a force to the palm of the hand, which pushes the wrist in extension, reduces EMG activity of most of the wrist extensor muscles during hand gripping at a given force. Interestingly, the 2 muscles with the most significant changes were the ECRB and EDC, which are the muscles that are affected in persons with lateral epicondylitis.[6]

These findings are in agreement with the work of Jansen et al[5] and Newport and Shukla,[8] who reported that gripping with a brace reduces the activity of the extensor muscles. However, instead of using a static brace with gripping[5] or a dynamic splint with passive extension,[8] we investigated the effect an external extension force would have on extensor muscle activity during gripping at 3 different wrist angles. Also the effect of different gripping intensities and different extension forces were assessed in the present study.

The reproducibility values, expressed as coefficient of variation or correlation coefficient, can be considered as average to good, which adds to the robustness of the data presented. The decline in EMG RMS

TABLE 5. Grip strength (mean [SD]) when gripping without and with a wrist extension force equal to 1%, 2%, or 3% of maximum voluntary contraction (MVC) in 3 different wrist angles (0°, 15°, and 30°) and at efforts equal to 3 different percentages of the MVC (10%, 20%, 30%).

Wrist Extension Angle	Grip Strength (%MVC)	Extension Force 0%	1%	2%	3%
0°	10	39.7 (13.8)	39.9 (13.3)	40.0 (13.7)	40.7 (13.5)
	20	76.4 (27.0)	76.6 (28.2)	76.4 (27.3)	76.0 (27.6)
	30	114.3 (42.6)	112.5 (40.8)	114.2 (40.9)	114.5 (42.4)
15°	10	39.7 (14.2)	40.0 (14.1)	40.1 (14.0)	40.8 (13.5)
	20	76.5 (27.8)	76.4 (27.6)	76.6 (27.5)	76.6 (27.8)
	30	113.1 (41.4)	113.4 (42.1)	113.4 (41.4)	113.5 (41.9)
30°	10	39.6 (15.5)	39.9 (14.7)	39.0 (14.4)	40.1 (15.3)
	20	74.8 (29.4)	75.0 (29.2)	75.4 (29.4)	75.6 (29.5)
	30	111.6 (44.2)	111.9 (43.9)	112.3 (44.2)	117.0 (40.9)

values when applying an extension force to the wrist was not the result of a difference in force generation during gripping. This is shown by the data in Table 5, which indicate that grip strength was very similar among the different measurements.

The extent of the reduction of muscle activity differs between the applied extension forces, grip intensities, and wrist angles. The positions of the arm and wrist in the present study were based on studies by Fong and Ng[4] and Barr et al,[1] who reported that grip strength is the highest with the wrist in 15° or 30° of extension and 0° of ulnar deviation, and that EMG values are lower when the arm is pronated compared to the neutral position. However, O'Driscoll et al[9] reported the highest grip strength between 25° to 35° of wrist extension angle. Low levels of MVC (10%, 20%, and 30%) were used to represent functional everyday gripping intensities.[2,10]

The results of this study show that a greater passive wrist extension force results in a higher reduction in muscle activity. The flexion moment that is produced by the flexor muscles when gripping is counterbalanced by an extension moment normally produced by the extensor muscles.[16] Therefore, increasing the external force results in a reduction in the extensor muscle force that is needed to balance the wrist flexor moment. Further research is needed to assess the optimal extensor force (ie, the force with the greatest reduction in EMG RMS values of the extensor muscles at similar grip strength generations and without any negative side effects on the flexor muscles). This is of special importance for brace development to treat patients with lateral epicondylitis.

Another interesting finding was that grip intensity also affected the results. If the flexion moment is increased due to a higher gripping intensity, then the extension moment must also increase to maintain equilibrium in the wrist.[14] Because the extension force is constant, only the muscle force can increase to maintain that equilibrium in the wrist. This means that a higher gripping intensity results in more muscle activity when a constant extension force is applied to the hand. Therefore, the highest decreases are to be expected with lower grip intensities, as was generally observed.

The highest decrease in muscle activity for the ECRB and EDC was shown gripping with the wrist in 15° of extension. The ECRL showed higher decreases at 30° of wrist extension. Because 15° approaches the normal functional wrist angle the best, the effect found at 15° has important practical and clinical implications.

Clinical Implication

The principle tested in the present study (ie, an extension force applied to the palm of the hand at different wrist angles to mimic a dynamic situation) may be of great value in treating patients with lateral epicondylitis. However, a clinical trial is required to evaluate the effect of such a dynamic extension brace in patients.

Limitations

Although the sequence of testing was kept constant, it is highly unlikely that this may have influenced the findings of the present study. The gripping periods were very short (5 seconds) and the levels of gripping strength were low (10%, 20%, and 30% MVC). In addition, 2 to 5 minutes of rest were applied between conditions, during which the wrist angle or extension forces were adjusted.

Because the purpose of this study was to test the principle that an extension force applied to the palm of the hand reduces extensor muscle activity, the study was performed with separate extension forces. Now that we know that this principle reduces muscle activity of the wrist extensor muscles, it may be a useful principle in the treatment of patients with lateral epicondylitis. In the future, a dynamic extensor brace has to be developed and evaluated in a clinical trial.

CONCLUSION

This study shows that an extension force applied to the palm of the hand reduces ECRB and EDC activity, as assessed by RMS values of the EMG signal, during gripping in healthy volunteers. A higher extension force resulted in a greater reduction in muscle activity.

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