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ORIGINAL ARTICLE

Evidence for repetitive load in the trapezius muscle during a tapping task

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Abstract Many studies describe the trapezius muscle activation pattern during repetitive key-tapping focusing on continuous activation. The objectives of this study were to determine whether the upper trapezius is phasically active during supported key tapping, whether this activity is cross-correlated with forearm muscle activity, and whether trapezius activity depends on key characteristic. Thirteen subjects (29.7 ± 11.4 years) were tested. Surface EMG of the finger's extensor and flexor and of the trapezius muscles, as well as the key on–off signal was recorded while the subject performed a 2-min session of key tapping at 4 Hz. The linear envelopes obtained were cut into single tapping cycles extending from one onset to the next onset signal and subsequently time-normalized. Effect size between mean range and maximal standard deviation was calculated to determine as to whether a burst of trapezius muscle activation was present. Cross-correlation was used to determine the time-lag of the activity bursts between forearm and trapezius muscles. For each person the mean and standard deviation of the cross-correlations coefficient between forearm muscles and trapezius were determined. Results showed a burst of activation in the trapezius muscle during most of the tapping cycles. The calculated effect size was $\geq$0.5 in 67% of the cases. Cross-correlation factors between forearm and trapezius muscle activity were between 0.75 and 0.98 for both extensor and flexor muscles. The cross-correlated phasic trapezius activity did not depend on key characteristics. Trapezius muscle was dynamically active during key tapping; its activity was clearly correlated with forearm muscles' activity.

Keywords Trapezius myalgia · Key tapping · EMG · Phasic activity

Introduction

Musculoskeletal complaints in the neck and upper extremity, particularly *trapezius* myalgia, are common events in modern society. There is evidence for a possible causal relationship between computer work and musculoskeletal diseases in the neck and arm (Ming and Zaproudina 2003; Wahlstrom 2005; Gerr et al. 2006). *Trapezius* myalgia is mostly associated with static work in front of a computer with a fixed posture, stressful jobs, and insufficient rest (Madeleine 2010). It has been suggested that individuals with a poor computer working technique work with higher muscle activity in the forearm and shoulder (Lindegard et al. 2003). Wrist and arm postures, finger movements, speed of movements, and force applied while keying are examples of variables included in this construct (Kadefors and Läubli 2002; Wahlstrom 2005; Gerr et al. 2006).

Good ergonomic conditions, the time-spent working with computers, and the influence of input devices are the most important aspects regarding work-related musculoskeletal diseases in the upper body. Observing subjects

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working with keyboards, a previous investigation showed that absence or presence of neck pain could be predicted by assessing if a neck flexion greater than 20° was present (Baker et al. 2008). A correct placement of the visual unit is therefore extremely important. A relationship between duration of computer use and prevalence of musculoskeletal problems has been previously reported (Ming et al. 2004; Bhanderi et al. 2008). Nevertheless, a recent review by Waersted et al. (2010) showed only limited epidemiological evidence for the association of computer work and some of the clinical diagnoses related to musculoskeletal complaints. Although it remains questionable as to whether computer work leads to clinical MSD diagnoses, a number of studies point out the interactions between neck and shoulder pain and *trapezius* as well as forearm muscle activation patterns: Subjects with more severe upper extremity symptoms apply more force while using the keyboard (Feuerstein et al. 1997). In addition, reduced intramuscular coordination between extensor and flexor arm muscles is present when using keys with high force characteristics (Tomatis et al. 2009). One of the functions of the *trapezius* muscle is the stabilization of the shoulder; hence it allows the stabilization of the arm. Recent findings suggest that pain-induced changes in *trapezius* activity also change the coordination of the wrist extensor and flexor muscles (Falla et al. 2004; Samani et al. 2011). Therefore, a dependency between forearm muscles and *trapezius* activation during key tapping is very plausible. We hypothesize that by applying higher forces or because of bad forearm muscle coordination (i.e., high co-contractions of agonist and antagonist muscles) while working with different key characteristics, higher muscle activation might be found in the *trapezius* muscle, since in computer operators pain in the forearm muscle is often accompanied by *trapezius* myalgia.

This study focuses on trapezius muscle load using input devices (keys with different force-displacement characteristics) and with supported forearm. In subjects with musculoskeletal diseases higher average *trapezius* activity and reduced rest time (prolonged periods without muscle relaxation) during work were already described (Vasseljen and Westgaard 1996; Hägg and Astrom 1997; Sandsjo et al. 2000; Thorn et al. 2007). Goudy and McLean (2006) stated that in computer workers pain-afflicted subjects differ from pain-free controls mainly in the amount of muscular rest time. The contribution of all upper limb joints, including the shoulder, to single-finger tapping has been investigated by Dennerlein et al. (2007) with motion analysis, showing that the shoulder contributes to a small extent to the tapping movement. As only the joint movement was recorded but not the muscle activity, we suggest that the muscle activation related to the tapping might be observable to a higher extent than the actual joint movement.We intended to identify phasic activity during tapping by assessing activity in the *trapezius* muscle during repetitive and fast tapping tasks. Specifically, the objectives were: (1) to determine whether the *trapezius* is phasically active during supported key tapping, (2) to determine if the *trapezius* activity depends on the forearm activity, and (3) to determine whether the strain intensity depends on the characteristics of the key.

Methods

Subjects

Thirteen right-handed subjects (seven women and six men) were included in the study, with the following anthropometric characteristics (mean ± SD): age 29.7 ± 11.4 years (ranging from 20 to 57 years) and height 171.8 ± 9.7 cm (ranging from 155 to 187 cm). All subjects worked at least 5 h per week at the computer. None of the subjects suffered from neck, shoulder, arm, or wrist pain.

The Ethics Committee of the ETH Zurich approved the study protocol, and informed consent to the procedure was obtained from all subjects.

The subjects were allowed to stop at any time in case of pain or fatigue.

Experimental design

The subjects sat with the right forearm supported on a table, the wrist sustained on a keyboard support, and the prone hand and fingers extended above the keyboard. The subjects had the possibility to adjust the chair to sit more comfortably.

The subjects were asked to depress the key with the index finger at a frequency of 4 Hz during 120 s while keeping the finger on the key. The pace was provided by audio signals. This tapping task was repeated once for each of the ten keys with different characteristics (Table 1) in random sequence (Tomatis et al. 2009) to avoid an order effect.

Table 1 Key force–displacement characteristics and labels

Key name	40 p	60 p	80 p	100 p	120 p	1 mm	2 mm	3 mm	4 mm	5 mm
Make-force (N)	0.39	0.59	0.78	0.98	1.18	0.59	0.59	0.59	0.59	0.59
Key displacement (mm)	3	3	3	3	3	1	2	3	4	5

The surface electromyogram (sEMG) of the finger extensor (*m. extensor digitorum*) and flexor (*m. flexor digitorum*) and of the *trapezius* (*m. trapezius descendens*) muscle was recorded, as was the key on–off signal.

Key characteristics

The keys differed in their force-displacement characteristics: five keys had the same displacement (3 mm) but differing in forces, and the other five had the same force (0.588 N), but different displacements (Table 1).

Electrodes

Conventional surface bipolar Ag/AgCl electrodes (20 mm apart, pre-gelled, 9 × 6 mm recording area, Medtronic, Switzerland) were used to record the sEMG signals.

Before applying the electrodes, the skin was shaved and prepared with a peeling paste. Bipolar electrodes were placed at a point 2/3 of the distance from C7 and the acromion (Jensen et al. 1993). Both the extensor and flexor application points on the forearm were found by palpation. A reference electrode was placed on C7.

Hardware

An eight-channel pre-amplifier (GAIN = 100) and an eight-channel amplifier with manual adjustment for amplification (10–50), a 30-Hz high-pass filter, a 300-Hz low-pass filter and a 50-Hz notch filter (Signal and Information Processing Laboratory ETH Zurich, Switzerland) were used to record the measurements. No ECG artifacts were observed by visual inspection.

A 12-bit A/D card (NI PCI-6023E, National Instruments, Austin, Texas) was installed on a 1.10 GHz personal computer (Windows XP) to sample and store the data. Data were stored at 2,048 Hz using custom software programmed with Matlab (Version 7.0.1, Mathworks, MA, USA).

Data analysis

The sEMG signals of the muscles *extensor digitorum*, *flexor digitorum* and *trapezius* were rectified and processed with a sixth-order Butterworth low-pass filter at 5 Hz to obtain linear envelopes, which provide information on the timing and duration of the burst, as well as details on muscle activation characteristics.

Using the onset signal of the key-tap, the linear envelopes obtained from each channel were cut from one key onset signal to the next one. To remove timing variability between the cycles, the envelope length was time normalized to 1,000 samples per cycle, using a re-sampling procedure.

For each condition and each subject, the limits for the outliers were defined as the 10th and 90th percentile of the amplitude range for every cycle. Outliers were excluded from the further analysis. For each session with a specific key characteristic approximately 400 until 500 cycles could be used. The normalized cycles were overlayed and the average activity level within a cycle was determined. At each point in time the mean and its standard deviation were calculated. The mean range over the tapping cycles was compared to its maximal standard deviation. The resulting quotient was used to describe the effect size of the observed *trapezius* activation (Leonhart 2004). The maximal amplitude of the averaged signal was used to characterize the phasic component of the *trapezius* activity. Therefore, the mean of the averaged signal was shifted to zero and the amplitude was normalized by setting the maximum to

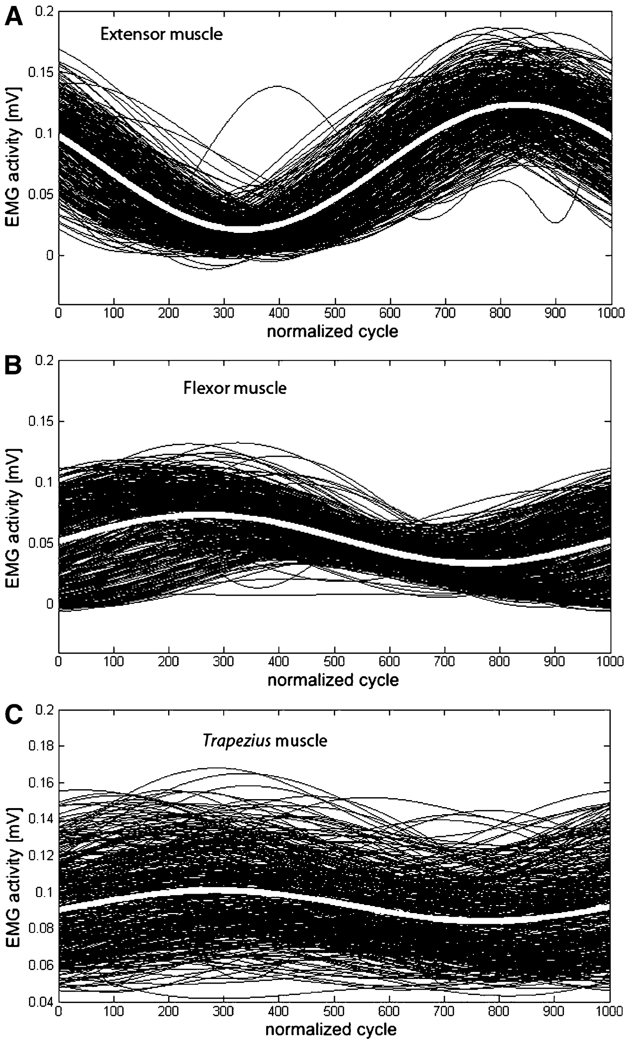

Fig. 1 **a–c** Depiction of the overlaid sEMG activities of the forearms and *trapezius* muscles during the tapping cycle of one subject. The *thick white line* represents the mean. The cycle period lasts approximately 250 ms divided into 1,000 normalized units

Table 2 Effect size and significance of cross-correlation

Person	Key name									
	40 p	60 p	80 p	100 p	120 p	1 mm	2 mm	3 mm	4 mm	5 mm
1	0.4*	2.86*	2.67*	3.03*	2.94*	2.99*	2.59*	2.17*	1.60*	1.64*
2	0.74*	0.96*	0.81*	1.11*	0.66*	0.94*	0.64*	0.62*	0.96*	1.08*
3	0.36*	0.50*	0.47*	0.71*	1.05*	0.66*	0.51*	0.94*	0.94*	0.13*
4	0.16*	0.47*	0.61*	0.24*	0.85*	0.46*	0.47*	0.86*	0.44*	0.36*
5	0.73*	0.33*	0.86*	0.52*	0.63*	0.60*	0.24*	0.43*	0.65*	0.81*
6	0.46*	0.53*	1.24*	0.92*	1.60*	1.51*	0.36*	0.29*	2.13*	0.49*
7	1.18*	0.28*	0.52*	1.29*	1.07*	0.30*	0.39*	0.35*	0.46*	0.91*
8	1.56*	1.92*	2.28*	2.54*	1.88*	1.24*	1.13*	0.84*	1.20*	1.18*
9	1.20*	0.53*	0.37*	1.52*	1.12*	0.97*	0.77*	0.93*	0.61*	1.38*
10	0.46*	0.45*	0.25*	0.11*	0.64*	0.43*	0.44*	0.62*	0.29*	0.40*
11	0.43*	0.27*	0.25*	0.65*	0.55*	0.41*	0.34*	0.53*	0.62*	0.46*
12	0.34*	0.14*	0.64*	0.74*	1.34*	1.03*	0.44*	0.63*	0.45*	0.38*
13	Miss	0.63*	1.28*	0.99*	1.29*	1.23*	0.74*	0.60*	0.82*	0.90*

* $p < 0.001\%$

100%. Thus, the resulting signal ranges from approximately −100% to a maximum of 100%.

Statistical methods

Statistical analysis was performed using SAS (Version 9.1, SAS Institute Inc., NC, USA).

To check if the activity bursts of the forearm and *trapezius* muscles are time-correlated during the tapping cycle, cross-correlation was used.

Mixed models statistics (proc mixed) were used to calculate exact *p* values and significances. The correlation coefficients determined by cross-correlation were regressed on the predictor key and order of key. Subjects were set as a random factor. Significance was assumed for $p \leq 0.05$.

Results

Objective 1: Phasic activation of *trapezius* muscle

Results showed a phasic activation of the *trapezius* muscle during the tapping cycle (Fig. 1). The calculated effect size was ≥0.5 in 67% of the cases (graphs), where a case is defined as all repetitions for one key and one subject (Table 2).

Objective 2: *Trapezius* activity depends on forearm activity

The size of the correlation coefficient determined by the cross-correlation between forearm and *trapezius* muscle activity ranged between 0.75 and 0.98 (mean 0.93 ± 0.05) for both the extensor and flexor muscle.

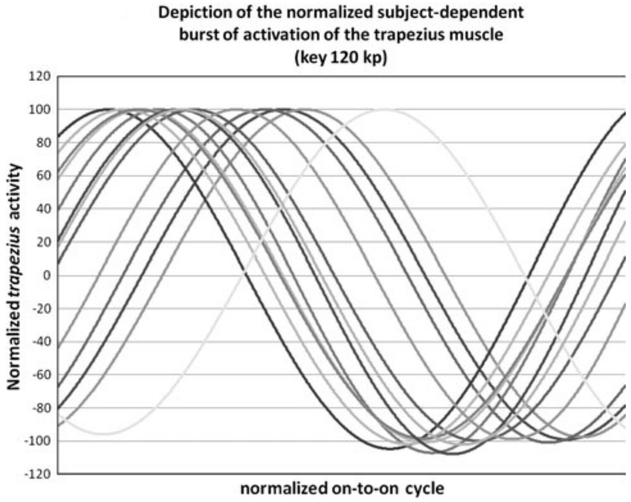

Fig. 2 Depiction of the burst of activation of all subjects during the tapping cycle obtained with the key characteristic 120 kp. Every cycle has been normalized for time and amplitude

Phasic activity of the trapezius muscle was nearly always detectable, but at significantly different time-points within the tapping cycle for the participating subjects (Fig. 2).

Objective 3: Dependency of *trapezius* activity to key characteristics

Mixed models statistics were used to examine the relationship between the timing of the *trapezius* activation and the different key characteristics. *Trapezius* activity did not

Table 3 Results of the mixed models statistic used to calculate the influence of different subjects and keys on the correlation coefficient of the flexor and extensor muscles

Variable	F	p
Flexor		
Subject	34.79	<0. 01
Key	1.71	0.10
Order	0.28	0.60
Extensor		
Subject	37.03	<0. 01
Key	1.66	0.11
Order	0.53	0.47

strongly depend on key characteristic neither for flexor muscle nor for extensor muscle (Table 3).

Discussion

Objective 1: Phasic activation of *trapezius* muscle

One of the aims of this study was to provide evidence for repetitive strain in the *trapezius* muscle during a tapping task. In 67% of the studied cases a burst of activation was detected with an effect size ≥0.5.

Increased phasic *trapezius* EMG activity during finger- or key-tapping was shown. In 2000, Schnoz et al. found elevated dynamic and static *trapezius* muscle activity during finger tapping at different rates and trunk postures that were not only explainable by mechanical reasons such as maintenance of body posture. In addition, Zennaro et al. (2003) found continuous active motor units during 30 min of key tapping, supporting the Cinderella hypothesis (Hägg 1991).

To exclude a possible correlation with the movement of the upper arm, we chose a setup with supported forearm and supported wrist. Under those conditions, shoulder and arm are almost immobile: no movement was visible during the tapping task. Nevertheless, we detected repetitive activation of the *trapezius* muscle in correlation with activation of the forearm muscles. The observed activity shows a phasic pattern and is highly time-correlated with the key on–off signal. Many studies showed generally increased EMG values during key tapping, describing a more or less static EMG component, for which the source remained unclear (Zennaro et al. 2003; Leonard et al. 2010; Madeleine 2010). In the experiment conducted, the tapping was performed with only one finger at a given speed. Therefore, the phasic activation of the *trapezius* could easily be measured. Thinking about a more realistic work task, most workers would use a ten-finger system while working with a keyboard. Using all fingers with some variation in speed should result in overlaying phasic activation patterns. Therefore, we hypothesize that a great part of the generally increased activity described in the aforementioned studies could be explained by the phasic activation as seen in our experiment. A possible explanation for the detected activity could be anticipatory postural adjustments (APAs) to stabilize the position of the segments of the body during movement (Massion 1992). Anticipatory postural adjustments are unconscious muscular activities preceding the voluntary movement aiming to prevent the changes in posture produced by the focal movement itself (Caronni and Cavallari 2009). In the year of 2009, Caronni and Cavallari conducted an experiment to investigate the role of APAs during index finger tapping. They showed that with the hand resting prone, APAs in *trapezius* muscle could not be observed. In contrast they found an inhibition of the *trapezius* prior to the finger tap in the prone position. As the subjects in the present study also performed the key tapping with the index finger in a prone position, APAs may not fully explain the activity found in our study.

Another explanation for the observed activity in the *trapezius* can be found in the literature describing motor learning:

Darainy and Ostry (2008) showed that following an arm movement learning task co-contraction of the shoulder still remained constant. In the initial phase of learning a new movement, very high activity can be observed in all muscles related to the movement, but co-contractions decrease with the learning progress (Thoroughman and Shadmehr 1999). According to Darainy and Ostry, these co-contractions do not disappear throughout the learning process but still form a central part of the means by which the nervous system regulates movement, also in highly skillful subjects. It seems that even though in our experimental setup the subjects were experienced keyboard users and performed the tapping task with supported forearm, the activation of the *trapezius* is not needed from a biomechanical point of view, but also cannot be avoided because it is part of the motor program controlling the movement.

Objective 2: *Trapezius* activity depends on forearm activity

The *trapezius* activity was found to be dependent on the forearm activity: cross-correlation ratios between forearm and *trapezius* activity were high for both extensor and flexor muscles.

Comparable results have been found by Schnoz et al. (2000) who showed that dynamic co-activity of the *trapezius* muscle occurs during computer mouse use and is time-linked with the mouse clicking. A recent publication of Samani et al. (2011) showed that artificially induced pain in the *trapezius* can lead to changes in the coordination of wrist flexor and extensor muscles. Thus, there seem to be strong interactions between the motor control of forearm and *trapezius* muscles, influencing each others' activation patterns. This hypothesis is supported by Alizadehkhaiyat et al. (2007), showing that a weak shoulder may predispose other joints, e.g., the elbow, to injuries caused by overuse.

This relationship might also explain the high inter-individual differences in the timing of the burst of *trapezius* activation that were found in the present study. Various individual conditions could influence the interactions between forearm and *trapezius* muscle activity: e.g., shoulder strength (Alizadehkhaiyat et al. 2007), shoulder pain (Samani et al. 2011), muscle imbalance in shoulder or forearm (Lewis et al. 2005) or level of forearm muscle coordination (Tomatis et al. 2009). These differences could explain why some subjects may be predisposed to easier MSD development caused by the mechanisms described by Sjogaard and Sogaard (1998).

Objective 3: Dependency of *trapezius* activity to key characteristics

No significant relationship between key characteristic and phasic *trapezius* activity was observed.

During the recent years, computer work time has increased (Dolton and Pelkonen 2004). Already in 2002, Kadefors and Läubli estimated that more than half of the population in Europe was using a computer at work. Extended periods of time are spent using input devices and, if some keyboards induce more muscular activity, the risk of MSD development could increase. To be able to reduce possible risk factors, the effect of different key characteristics on the *trapezius* activity is of great interest.

As shown in Table 3, our experiments could not show any relationships between phasic *trapezius* activity and key characteristics. Therefore, within our experimental conditions, a different keyboard does not seem to influence phasic *trapezius* activity. It has to be taken into consideration, that we only analyzed the time component of the muscle activity. There might be some changes in *trapezius* EMG amplitude induced by the different key characteristics. Further analysis should be made to provide more information about possible differences in EMG amplitude.

Limitations

There might be some concerns about the subject's body position, as it was not fully controlled. As aforementioned, a comparable activation pattern of the *trapezius* muscle was found in most of the subjects, leading to the conclusion that the observed activity is mainly caused by the tapping process and not by posture. Nevertheless a possible influence of the posture on the trapezius activation and time shift cannot be fully excluded and has to be considered as a limitation of the study.

Cross-correlations were used to assess the dependency between *trapezius* and forearm muscle activity. This procedure provides only a linear relationship between the timing of the measured EMG activation patterns. Even though the correlation parameter were very high (0.93 ± 0.05), the effect might be overestimated. Principal component analysis (PCA) would be an alternative to gain more detailed information about the dependencies of muscle activation timing and could be used in future studies.

Conclusion

Our experiments showed phasic *trapezius* activation during a tapping task with supported wrist and forearm. This *trapezius* activity is highly correlated with the finger flexor and extensor activation. The causes for this activity and whether it could be seen as a primary cause for developing pain should be further investigated.

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