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Research article

Time constraint and error corrections contribute to the increase of hand postural tremor during mental calculation

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ABSTRACT

Purpose: Hand postural physiological tremor increases during arithmetic computation. The present work aims at investigating whether this could be attributed to a raise in stress for having to provide a correct answer within a constrained period of time, or to voice vibration for having to speak to report the answer.
Methods: In 16 participants tremor was recorded by using a 3-axial accelerometer during 5 min of a hand postural task performed simultaneously while: 1) subtracting 13 from a 3-digit number within 4 s and with mistakes correction (intervention: math stress task), 2) same as for the "intervention task" but without time limit and mistakes correction (intervention: math nonstress task), 3) adding 1 to a 3-digit number (intervention: voice vibration task), and 4) only postural task while keeping quiet (control task). Electromyographic (EMG) activity from the extensor carpi radialis was measured during the hand postural task.
Results: Compared to control, tremor increased during both math interventions (+30.9 % $p = 0.002$, math stress; +15.0 % $p = 0.01$, math nonstress), but not during the voice vibration task (+12.2 % $p = 0.239$). During the math stress trial tremor was greater compared to both the voice vibration trial (+21.0 % $p = 0.021$), and the math nonstress trial (+13.5 % $p = 0.01$). EMG activity was not affected.
Conclusion: The results suggest that during arithmetic computation the "stress component" contributes only partially to the observed increase in hand postural tremor, and that this increase cannot be attributed to voice vibrations.

Abbreviations

EMG	Electromyography
RMS	Root mean square
SD	Standard deviation
ANOVA	Analysis of variance
ES	Effect Size

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1. Introduction

The execution of a purposeful movement, from the easiest to the most complex, is associated to a cognitive component that can be observed by electrocortical activity. Consequently, it is not surprising that when a motor and a cognitive task are executed simultaneously, either one of the two tasks, or both, might be negatively affected [1–4].

Although the exact underlying mechanisms are yet to be determined, this effect is attributed to the so-called cognitive-motor dual-task interference, and it is suggested that such interference is the consequence of resources having to be re-allocated between tasks [5], creating a bottle-neck effect due to multiple information being processed by similar neural networks [6].

We have recently demonstrated that also postural physiological tremor is affected (increases) during a mental task [7]. However, since physiological tremor is not volitionally controllable [8], this result should be attributed to mechanisms other than cognitive-motor interference.

The mental task performed during the assessment of tremor in our previous work [7] involved arithmetic computations (continuously subtracting 13 from a 3-digit number), and the participant was required to provide the correct answer within 4 s. These methodological conditions are also commonly adopted as stressors in experimental settings to induce and study stress or anxiety in the participant [9]. Since stress is also known to stimulate the sympathetic nervous system [10] with related release of catecholamines, which could in turn increase muscle tremor [11–13], it could be suggested that the increase in tremor we observed during the metal task [7] was induced by an increase in stress with related release of catecholamines.

Alternatively, another element that might have influenced the results, can be linked to the methodological necessity for the volunteer to speak during the intervention (mental calculation) and not during the control condition. Indeed, study participants were not just required to think about the question and formulate the answer, but also to communicate it to the investigator. Speech production involves the formation of thoughts to be expressed, choice of words and ultimately the vibration of vocal cords [14]. It could therefore be suggested that the sound produced by the responses induced a rhythmical oscillation that could have entrained with the natural oscillation of the investigated limb, in a similar way mechanical oscillations can entrain with servo feedback loops, resulting in an increase of tremor [15–20].

The primary aim of this research is therefore to determine whether the augmented physiological tremor during the postural contraction [7] should be attributed to the mental task per se or to augmented stress/anxiety levels induced by it. Secondary, we will try to understand whether voice vibrations also contribute to enhance tremor or not.

2. Methods

2.1. Participants, study design and procedures

Sixteen participants: 12 males (31.7 ± 8 years, 76.0 ± 7.7 kg, 183 ± 6 cm) and 4 females (28.8 ± 3 years, 60.8 ± 8.1 kg, 166 ± 4 cm) were recruited among colleagues and university students and agreed to volunteer for the experiment. The participants were recreationally active (not practicing any sport at competitive level, but engaged in physical activities at least two times a week), and did not have any history of neurological disorders officially documented by a neurologist. Participants were asked to withhold from any major physical activity on the day of testing and withhold from caffeine and nicotine in the 2 h preceding the test. The study was conformed to the standards set by the declaration of Helsinki and approved by the local Ethics Committee. Participants provided written inform consent before the onset of the experimental procedures.

Measurements were performed in single experimental session, lasting about 50 min. After preparation for electromyography (EMG)

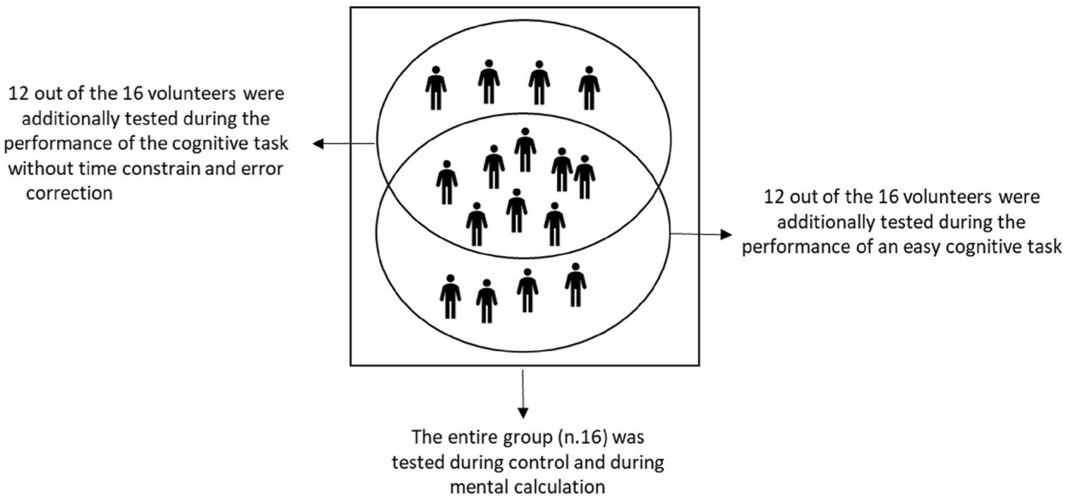

Fig. 1. Subgroups organisation.

Table 1
Summary of required tasks.

	Task requirement				Statistically different from			
	Hold a posture	Verbalize the answer	Perform difficult arithmetic computation	Experience significant stress	Control	Voice Vibration	Math nonstress	Math stress
Control	X						X	X
Voice vibration	X	X					X	X
Math non-stress	X	X	X		X	X		X
Math stress	X	X	X	X	X	X	X	

recording, hand postural tremor was measured during mental calculation (Intervention group “math stress”) or without mental calculation (“control” group). As depicted in Fig. 1, in a subgroup of 12 volunteers (31.8 ± 8 years, 73.0 ± 8.7 kg, 179 ± 8 cm, 2 females) we run a further measurement also during a simple mental calculation task (Intervention group “voice vibration”). In another subgroup of other 12 volunteers (30.4 ± 7 years, 72.8 ± 11.4 kg, 178 ± 10 cm, 4 females), supplementary recordings were done during a nonstress cognitive task (Intervention group “math nonstress”). (All details in the paragraph “*Intervention protocols*”). All measurements were conducted in random order.

2.2. Postural tremor

The participants sat on a chair with their forearm supported by the armrest but without any support for the hand. They were instructed to keep the hand horizontal with the palm facing down and in line with the forearm and to maintain the fingers extended. A 3-axis accelerometer (MPU– 6050, SparkFun Electronics ®, 0.013 Kg of mass) secured to the hand with the z axis perpendicular to the ground, was used to record tremor continuously for 300 s.

2.3. Intervention protocols

For the math stress task, participants were asked to continuously subtract the number 13 starting from a randomized 3-digit number (e.g., 834–821 – 808 - …) within 4 s for each calculation. Participants had to start again from the beginning when they miscalculated or exceeded the 4 s time limit (“math stress” group). On 12 subjects we additionally tested the effect of the same cognitive protocol, with removal of the possible “stress-component” related to the time constraint and the correction of mistakes (“math nonstress” group). In this case we did not apply time restrictions for the answer and did not correct in case of mistaken answer. The volunteer could therefore continue the calculations without any hurry, interruptions, or having to restart the counting.

To exclude that any variation in the amplitude and frequency of the postural tremor could have been induced by voice vibrations, on 12 volunteers we additionally measured postural tremor during a task consisting in adding 1 to a 3-digit number (“voice vibration” group). In this case the cognitive effort was minimal, but the voice vibrations were comparable.

In Table 1 are summarised the different tasks required for the different tested conditions (and also anticipates the results in an overview).

2.4. Electromyography

Bipolar surface EMG was collected from the extensor carpi radialis brevis using adhesive electrodes (Blue Sensor N, Ambu A/S, Ballerup, Denmark). Electrodes were placed in correspondence of the main muscle bulk at about one third of the line connecting the humerus lateral epicondyle and radius styloid process, with the hand pronated. The ground electrode was placed over the olecranon process of ulna. The isolation amplifier limited the bandwidth with 60 kHz, without applying a of a low pass filter.

2.5. Data analysis

The acceleration and EMG signals were captured at a sampling rate of 1000 Hz (acceleration) or 2000 Hz (EMG) using the CED Spike 2 V10 package, stored on a PC and analysed in MATLAB (R2019a).

The standard deviation (SD) of the band-pass (2–30 Hz) filtered (Chebyshev Type I filter) acceleration signal was used to quantify postural tremor [21]. Frequency analysis was also performed (2048-point, hamming window with 50 % overlap fast Fourier transform) to identify position and amplitude of the dominant peak within 6 and 13 Hz.

Following offset removal from the raw EMG signal, the root mean square (RMS) of the EMG was calculated for the total 300 s contraction to assess muscular activation during the postural task.

2.6. Statistical analysis

Due to the participants’ allocation, two analyses were performed. In Analysis I, data from twelve participants that all performed control, math stress, and math nonstress conditions were analysed. In Analysis II, data from twelve participants who all performed control, math stress, and voice vibration conditions were analysed. Data distribution was checked by Shapiro-Wilks. A Friedman test with Wilcoxon signed ranks test for pair comparison was adopted for all data with a skewed distribution (SD of the acceleration, magnitude of the dominant frequency peak and EMG RMS) and the effect size (ES) was computed for each comparison. The primary frequency peak position was the only parameter normally distributed and was consequently analysed with an ANOVA for repeated measures. P-values <0.05 were defined as statistically significant.

3. Results

3.1. Analysis I: Control, math stress and math nonstress

Hand postural tremor amplitude was affected by the procedures ($\chi^2_3 = 15.167$, $p = 0.0005$) with the greatest difference (+30.9 % increase in the SD of the acceleration) observed between control and math stress ($Z = -3.059$, $p = 0.0022$, $ES = -0.62$). A significant increase in the SD of the acceleration signal was also detected between control and math nonstress condition (+15.0 %) ($Z = -2.589$, $p = 0.0096$, $ES = -0.53$) and between math nonstress and math stress condition (+13.5 %) ($Z = -2.589$, $p = 0.0096$, $ES = -0.53$) (Fig. 3A).

The magnitude and the position of the oscillation main frequency peak was not different between the tested conditions ($\chi^2_3 = 1.167$, $p = 0.558$ and $F = 2.972$, $p = 0.072$, respectively).

The EMG RMS of the extensor carpi radialis was 0.063 ±0 .028 mV during control condition and did not change during the interventions (0.059 ±0 .023 mV math stress0.062 ±0 .017 mV, math nonstress) ($\chi^2_3 = 0.167$, $p = 0.920$).

3.2. Analysis II: Control, math stress and voice vibration

Tremor did not increase during the execution of the voice vibration intervention. Significant differences were in fact detected ($\chi^2_3 = 11.636$ $p = 0.0030$) between control and math stress (+35.8 % in the SD of the acceleration) ($Z = -2.756$, $p = 0.006$, $ES = -0.59$) as well as between the voice vibration task and math stress (+21.0 %) ($Z = -2.312$, $p = 0.021$, $ES = -0.49$), but not between control and the voice vibration (+12.2 %) ($Z = -1.177$, $p = 0.239$, $ES = -0.24$) (Fig. 3B).

The group average main frequency of the oscillations ranged between 7.2 and 7.4 Hz among the three conditions, without showing

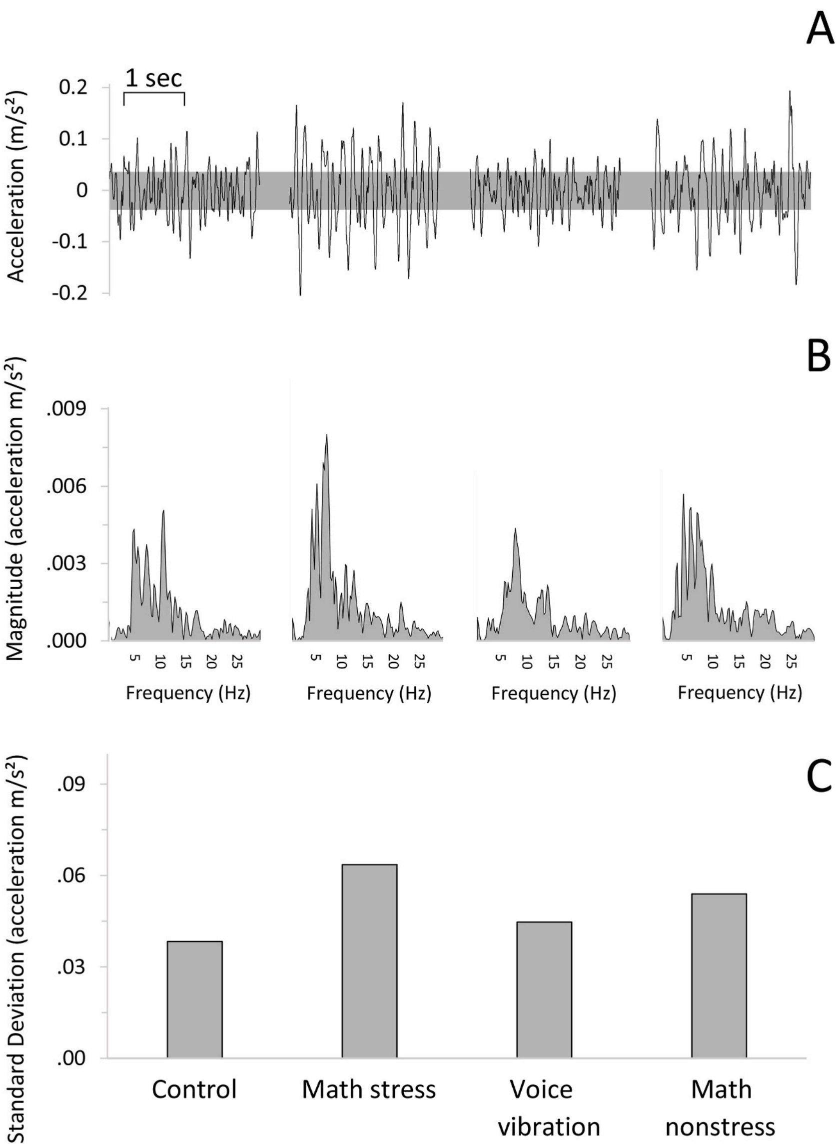

Fig. 2. Data from one representative subject, comparing control, math stress, voice vibration, and math nonstress conditions. **A:** 2.5 s of raw acceleration signal. The grey shade represents the average oscillation amplitude during the control condition. **B:** power spectrum of the acceleration signal. **C:** Standard deviation of the acceleration signal.

any shift (F = 0.297, p = 0.746). The dominant peak amplitude increased significantly during the math stress in comparison to the voice vibration (Z = −2.667, p = 0.008, ES = −0.57), but not between control and math stress or control and the voice vibration.

Also in this case, the EMG RMS of the extensor carpi radialis did not change in response of the procedures ($\chi^2_3 = 0.350$, p = 0.839) (0.070 ±0 .044 mV, 0.069 ±0 .038 mV, 0.067 ±0 .033 mV, during control, math stress, and voice vibration respectively).

4. Discussions

The current study was conducted to understand whether the increase in hand postural tremor observed during mental calculation can be attributed to stressor elements or to the methodological requirement for the subjects of having to communicate the calculation verbally, compared to not having to talk during the control condition. The results, summarised in Fig. 2A, B and 2C for a representative subject, show that: 1) the "stress component" seems to contribute only partially to the increase in tremor, and 2) the increase in muscle tremor observed during mental calculation cannot be attributed to voice vibrations.

The onset, or the exacerbation of tremor during a mentally demanding task has already been regularly reported for pathological tremors [22–26], but, excluding our recent work [7], to our knowledge no other studies investigated the effects of mental performance on physiological tremor. Nevertheless, despite the aetiological differences, both pathological and physiological tremor are affected by stress [23,27,28], therefore, since the performance of a mental demanding task is considered a standard psychological stressor [9,29, 30], it seems straight forward to attribute the increase in tremor to the increase in stress-induced sympathetic response, with related rise of circulating sympathetic hormones [22]. However, it must be questioned whether the nature of the stressor adopted in our study led to a physiological outcome sufficient or appropriate to influence tremor. Indeed, different stressor tasks can elicit different physiological responses that can be either only cardiovascular, or both cardiovascular and hormonal [10,31–33], yet, only hormonal responses are consistently related to an increase in tremor [34–36]. Moreover, in the case of a hormonal response, a further consideration still needs to be done about the amount of the circulating hormones and the time lag between the stressor and the potential endocrine response. In a study by Frankenhaeuser and Johansson [37] for example, adrenaline levels increased from 2.8 μg/min during inactivity/control to 4.5 μg/min during a cognitive task, and such increase might not be sufficient to have an effect on muscle tremor [11,12]. Additionally, although not exactly quantifiable, it takes time before elevations in stress hormones (at least cortisol) in response to acute stressors can be detected [38,39], consequently the timing of the assessment might have not been appropriate for capturing a hormones-induced effect. Therefore, the explanation of our results based on the seemingly obvious consequentiality of factors: "stress task = more hormones = more tremor", does not seem free from critical considerations.

Our data recorded during the math nonstress task, when the participants performed the arithmetic without time constraint or errors corrections, partially support these reflections about the possibility that tremor was not exclusively enhanced, as a response to an increase in stress. Indeed, as shown in Figs. 3A and 2, tremor during the math nonstress task was significantly greater compared to control, however, it was also significantly smaller than tremor during the math stress task. This may suggest that either only part of the intensification of tremor can be ascribed to stress and the other to the actual mental effort, or that the task that we considered as "nonstress" represented instead also a stressor of lower intensity. This latter hypothesis could find confirmation in previous works [4, 30] in which a complicated and an easy mathematical task (subtractions of −13 and −1 respectively) were also tested, resulting in a greater increase in stress and anxiety [4], blood pressure and heart rate [4,30] during the more challenging mental effort. Similarly, Earle and colleagues [10] reported weaker cardiovascular responses (blood pressure and heart rate) in their control group who performed only mental arithmetic, compared to the intervention group in which the subjects were harassed by the experimenters during the mental arithmetic. All of this would suggest that a less intense stressor induces a less intense response. However, Earle and colleagues [10] additionally reported that only the harassed group showed cortisol levels higher than baseline, and, as mentioned before,

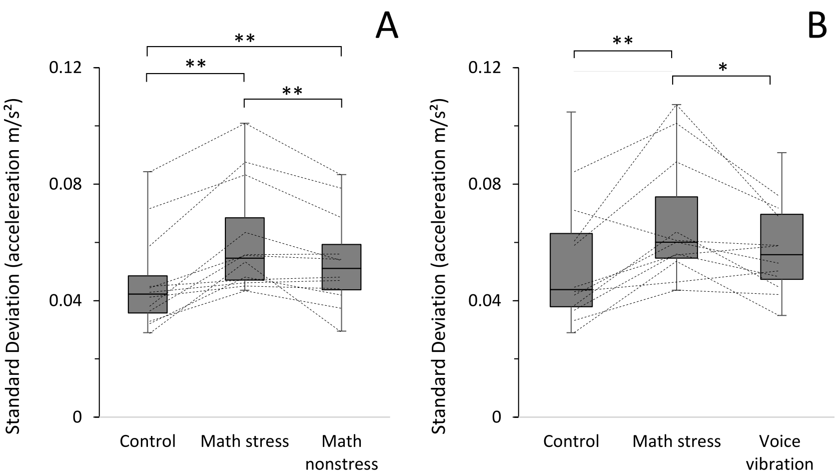

Fig. 3. Standard deviation of the acceleration data comparing control, math stress and math nonstress conditions (**A**) and control, math stress and voice vibration task (**B**). Individual values are represented with dotted lines.**p < 0.01; *p < 0.05.

cardiovascular responses alone do not correlate well to tremor as hormonal status does. Finally, in our previous work [7] we observed an increase in tremor during a postural task identical to the one tested in the current experiment, but we did not observe any increase in tremor during a goal directed kinetic task. If tremor was exacerbated by a hormonal reaction, we should have observed a more systemic response influencing both postural and kinetic tremor.

Based on our result of the "voice vibration" task (adding 1 to a 3-digit number) on tremor, the possibility that voice vibrations influenced the amplitude of the hand tremor can also be ruled out. An alternative explanation is therefore necessary, and studies on cortical activation during mental effort might shed light on our results.

A mental processing load, like the one required to solve a mathematic task, is accompanied by changes in electroencephalographical activity within the alpha band (8–13 Hz) [40] and the entity of such changes is influenced by task difficulty [41]. Similarly, increased brain activity in the alpha frequency band has been described during prolonged attention efforts [42,43]. Some evidence, although inconsistent, report presence of alpha band cortico-muscular and cortico-tremor coherence during isometric contractions [44,45], supporting the suggestion of a contribution of the motor cortex oscillatory activity to physiological tremor [46,47]. Grounded on this, it can be speculated that mental arithmetic increased tremor in response to changes in brain activity coherent with motor units firing rate within the physiological tremor frequency band. Further investigations are however necessary to prove this hypothesis.

5. Limitations

In the present study information about participants' academic background was not collected, and we cannot exclude that our results could have been influenced by this factor. Moreover, a limited number of subjects were tested, therefore it cannot be excluded that the study was underpowered to detect differences between the control and the voice vibration condition, limiting the validity of the assumption that the "voice vibration" task does not increase tremor, also considering that this task too, requires, although to a limited extent, a cognitive effort. Additionally, the "math nonstress" task might have in reality been stressful, but we were unable to quantify it; therefore, the extent to which the increase of tremor is due to cognitive load or to stress remains unclear. To overcome this, a future study could be structured to try to avoid completely any effect of stress related to having to perform math calculation in front of an experimenter, by for example having the participants to compute the subtraction mentally, without reporting the results, and with the experimenter blind to the participants' task.

6. Conclusions

The present study demonstrated that complex mental calculation, with or without the stress related to having time constraint and mistake corrections, increases hand postural tremor compared to controlled conditions without mental calculation. However, the more stressful condition in associated to greater increase in tremor. A simple mental task, used to verify whether tremor was affected by voice vibration, did not have an effect on tremor. It is hypothesised that the observed results could be attributed to changes in cortex oscillatory activity at tremor frequency.

Declarations

This study was reviewed and approved by the local Ethics Committee of the University of Graz, with the approval number: GZ. 39/128/63 ex 2020/21.

All participants/patients provided informed consent to participate in the study.

Data availability statement

Data available on request from the authors.

Funding

N.A.

CRediT authorship contribution statement

Francesco Budini: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Richard Mocnik:** Data curation. **Markus Tilp:** Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Domenico Crognale:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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