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Communication

# Transient effect of low-intensity magnetic field on human motor control

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**Abstract**

There is no consensus with respect to how extremely low frequency (ELF) magnetic fields (MF) affect biological systems. However, this information is crucial to establishing new guidelines for: (i) the new design of electronic devices, (ii) working conditions of exposed workers (e.g. electric linepersons), and in a general manner (iii) policies for human risk management. This study evaluates the effect of a sinusoidal 50 Hz, 1000 μT MF centered at the level of the head on human postural tremor of the index finger, using the wavelet analysis method. In addition to the detection of transient events in tremor time series linked with MF, this method was used to evaluate the differences between MF "on" and "off" conditions and between real and sham exposure in a counterbalanced protocol. Results indicate that neither transient events nor "off–on" or "on–off" MF transition effects were present in the postural tremor time series. Surprisingly, an unexpected significant time dependent decrease in tremor average power was noted along the 20 s recordings. Interestingly, this effect was significantly more pronounced in the presence of MF. These results suggest a relaxing effect of ELF MF on motor control resulting in an attenuation of postural tremor intensity.


*Keywords:* Postural tremor; Wavelet analysis; ELF magnetic field; Relaxation

## 1. Introduction

Distribution and transport power lines or domestic electric appliances are some of the numerous environmental sources of extremely low frequency (ELF, 50 Hz in Europe and 60 Hz in North America) magnetic fields (MF). For example, workers in electric companies work in the immediate proximity of equipment producing alternating currents and can occasionally be subjected to MF of 1000 μT [1,2]. Moreover, when people use an electric shaver, a hairdryer or a hair clipper, the MF generated on the surface of the apparatus can reach 1500–2000 μT [3,4]. In spite of their ubiquitous presence in our environment, the effects of ELF MF on human physiology are still unclear and more research is required [5]. Several studies have examined the effects of MF via electroencephalogram (EEG), electrocardiogram (ECG), cognition, evoked potentials or motor behavior, but no consensus has been established yet regarding their possible effects on human behavior (see [6,7] for a review). Moreover, most of the studies evaluate the effect of MF before and after but rarely during the exposure, due to the presence of artifacts in the recorded data caused by the MF itself (see for example [8]). However, it is necessary to have precise information concerning the effects of ELF MF on human central and peripheral nervous systems during the exposure [5]. One way to proceed is to study the nervous system output: motor behavior.

Among the few studies that explored ELF MF effects on human motor control, Thomas et al. (2001) showed that normal human standing balance can be improved by a specific 200 μT pulsed MF centered at the level of the head

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[9]. Another highly sensitive motor control parameter is human physiological tremor. Briefly, physiological tremor is an involuntary, irregular and continuous movement of a body part [10]. It is characterized by its amplitude (generally weak and variable between persons) and by its frequency (generally organized around 8–12 Hz [11]). The central and peripheral nervous systems contribute to the production of physiological tremor [11–14] in proportions which vary according to environmental and health conditions, but three main mechanisms are described (see [11,12,15,16] for a review): (1) mechanical resonance of the limb (around 17–30 Hz for metacarpophalangeal joint [17]), (2) feedback resonance and (3) central oscillations. Feedback resonance is itself represented by three feedback loops: (i) the short latency spinal reflex arcs from afferent stretch receptors, (ii) the long loop transcortical or transcerebellar reflex pathways from these receptors, and (iii) central feedback from motor neurons via the spinal cord. The loop time for spinal segmental stretch reflex in the finger is about 50 ms, and favors the generation of 10 Hz tremor [18]. More than 37 known factors are able to modify physiological tremor [19], and these modifications appear sometimes in the amplitude of tremor and sometimes in its frequency organization. Therefore, physiological tremor is highly sensitive to modifications in a person's neurophysiological state and constitutes a valuable parameter to detect the acute effects of ELF MF exposure on humans.

In previous studies, we explored the effects of a 1000 μT, 50 Hz MF, corresponding to the highest intensities commonly present in our daily environment, on human tremor [20,21]. Although our results showed a significant difference in the spectral content of human postural tremor across conditions when the MF was present versus absent, no clear MF effect has been established [20]. One of the limitations of this study was the absence of analysis of the effect of MF transitions: whether or not human motor behavior was transiently modified when the MF was switched "on" or "off" (see Fig. 1 for MF arrival illustration). Indeed, Thomas et al. (2001) estimated the delay of action of their MF on human postural sway between 3 and 43 ms [9]. Contrary to our previous study [20] the effect persisted during MF exposure, raising the question: "could such a short latency effect be detected if it does not persist in time?" Therefore, a detailed study of MF transitions might be helpful to evaluate and characterize the effect of MF on biological systems. Indeed, studies using intermittent exposure (1 s "on" and 1 s "off" for example [22,23]) to ELF MF seem to show more reliable results (see [6] for a review), which could mean that MF effects would be maximized when the field is turned "on" or "off".

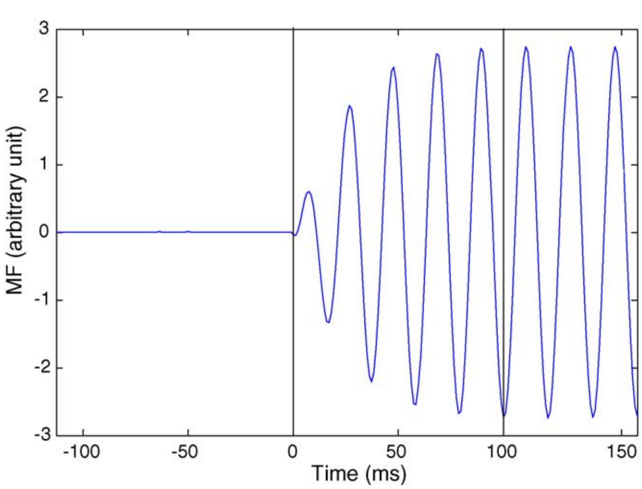


Fig. 1. Zoom on the MF "off–on" transition. The MF takes 100 ms to reach its maximum peak value (after five cycles at 50 Hz, period included between the two vertical lines).

The nervous system is considered as a preferential site of interaction with ELF MF because the tissues involved are sensitive to electrical signals. Various possibilities could be considered including a delayed or transient effect of MF on the stretch reflex and a delayed action on a central oscillator modulating physiological tremor. Thus, the main purpose of this work is (1) to investigate whether or not the exposure to a common environmental ELF MF can be detected in human physiological tremor by studying potential transient MF effects on postural tremor induced by its sudden arrival or departure and (2) to confirm or rebut the absence of MF effect during the exposure previously found [20].

## 2. Materials and methods

### 2.1. Subjects

Thirty-six volunteers, all men between the ages of 20 and 50 years (37.8 ± 8) were recruited from the personnel of a French electric company ("Eléctricité de France": EDF) and completed the experiment. None of them had previously taken part in studies involving MF exposure. Before testing, they were required to complete a screening questionnaire to ensure that: they did not use drugs or medications regularly; they had never experienced an epileptic seizure; they had no limitation of hand or finger movements; they did not suffer from chronic illness (e.g., diabetes, psychiatric, cardio-vascular or neurological diseases); they had no cardiac or cerebral pacemaker; and they had no metallic implant in the head or in the thorax. This information was verified by EDF's occupational medical service. All subjects were asked to refrain from smoking or drinking coffee the morning of the experiment. The study's protocol was reviewed and approved by the Operational Committee for Ethics of the life sciences section of the CNRS (Centre National de la Recherche Scientifique, France).

### 2.2. Procedure/experimental design

Subjects were tested at the same time of day (9:00 am) during a single session [24] and no artificial light was used [25]. The room temperature was controlled at 23 °C [26]. Before testing, subjects confirmed and signed the screening questionnaire, read the information form and signed the consent form. Their handedness was determined thanks to the Oldfield questionnaire [27]. After completing these requirements, they sat on a plastic chair placed in the middle of the MF generating device. Their dominant forearm was placed in a prone position on an armrest and the tested dominant hand was placed with the palm facing toward the ground on a molded clay support. The armrest was adjustable according to each subject's morphology. A piece of white cardboard (<1 g) was fixed on the index finger nail 10 cm from the metacarpophalangeal joint. A Class II laser diode (Micro laser sensor LM10, series ARN12, Matsushita Electronic Work, Ltd., Osaka, Japan) located vertically 8 cm above the piece of white cardboard and pointing towards the ground, transmitted a beam recording the vertical displacement. The laser used was an analogue output sensor with an optical triangulation range measurement system. Its resolution at the observed frequencies was 5 μm. The laser was calibrated with a micrometer prior to each testing day. An oscilloscope, placed one meter in front of the subject displayed a horizontal target line and gave visual feedback of the index finger's vertical position. An infra-red probe was fixed on the tip of the non dominant thumb to monitor heart rate and a temperature probe was fixed on the palm side of the wrist to record skin temperature.

The subject and the experimenter wore earplugs and an anti-noise helmet in order to be isolated from environmental noise. Subjects participated in a single session of 65 min including two sequences of postural tremor recording (i.e. tremor occurring while subjects had to maintain a fixed position with their index finger): postural tremor during a real and during a sham MF exposure sequence (Fig. 2a). Two sequences of kinetic tremor (tremor occurring while subjects had to track a target with their index finger) were also given, but in the present work, we only focus on postural tremor and results regarding kinetic tremor are developed in other works [20,21]. Sequences lasted 14 min each and were separated by 3 min rest. The order of presentation of these sequences was counterbalanced to avoid introducing an order effect. Each sequence was composed of four 62 s recording periods centered on a MF transition ("off–on" or "on–off", see Fig. 2b). Therefore, during each sequence, there were four MF transitions (two "off–on" and two "on–off"). The course of each experimental session was entirely programmed and was controlled by the computer: neither the subject nor the experimenter knew when the MF was really present. However, the MF was recorded during all the tests, which allowed a posteriori verification of its status to ensure that it corresponded to the explored conditions. Under sham and real sequences, the recording periods were the same but the MF was "off" during sham sequences.

Only 24 subjects satisfied the inclusion and exclusion criteria. Subjects were asked to relax and point their index finger in front of them without hyperextending it. They had to control their finger position by maintaining alignment between the feedback line and the horizontal reference line displayed on the oscilloscope. Only 20 s of recording centered on a MF transition were kept for analysis. Thus, the experimental design was AB BA AB BA with repeated measures. Each AB or BA corresponded to a 20 s recording of tremor in which condition A corresponded to 10 s with the MF "off" and condition B correspond to 10 s with the MF "on".

### 2.3. Field exposure system and data recording

The exposure device was developed by the "Institut de Recherche d'Hydro-Québec" (Qc, Canada) and is described elsewhere [20,28]. Briefly this system generated a continuous and homogenous sinusoidal 50 Hz MF of 1000 μT centered at the level of the head (but the trunk and arms were also exposed). The magnetic flux density was checked at the beginning of each session. The ambient geomagnetic field measured in the testing room with a handheld digital magnetometer μMAG-02WB (Macintyre Electronic Design Associates Inc., Dulles, USA) was 23 μT along the vertical axis, and 43 μT along the horizontal axis (total = $\sqrt{23^2 + 43^2} = 48.76$ μT). It was oriented at 23° compared with the alternating MF generated by the exposure device. Background ambient alternating MF were measured with an EMDEX Lite monitor (ENERTECH Consultants, Campbell, USA) and were less than 0.01 μT.

Tremor was recorded by a data acquisition system (DOCO Microsystèmes Inc., Montreal, Qc) sampled at 1000 Hz. Data were first transferred to Matlab (The MathWorks Inc., Natick, USA). A/D volts was converted to mm (calibration constant = 3.97) and velocity data was obtained by differentiation of the raw displacement data. Finally, displacement and velocity time series were cut in order to keep only the 20 s needed for analysis. Wavelet analyses were realized under LINUX environment with a program developed in Pau University, France.

### 2.4. Wavelet analysis

The main aim of this study was to determine if the transition of the MF could have a transient effect on postural tremor, and if changes in tremor are or are not more characterized by changes in its frequency. In order to do so, we needed a method likely to characterize transient changes of postural tremor time series both in time and frequency. Due to its local (time) and multi-scale (frequency) properties, wavelet transform (WT) is particularly well suited for time-frequency analysis and detection/quantification/characterization of singularities in non-stationary signals. Since its introduction by Morlet in 1982 [29], WT has found wide application in diverse fields of geosciences (e.g. [30]), but also in physiological studies (e.g. [31]). For a simple and clear presentation of WT see for example [27,32].

The WT of a signal $f(t)$ is the convolution with an analyzing wavelet function $\psi(a, t)$ where $a$ is a scale parameter (e.g. [33]). The signal is transformed into a set of coefficients $W$ called the "time-scale" representation of the signal. As

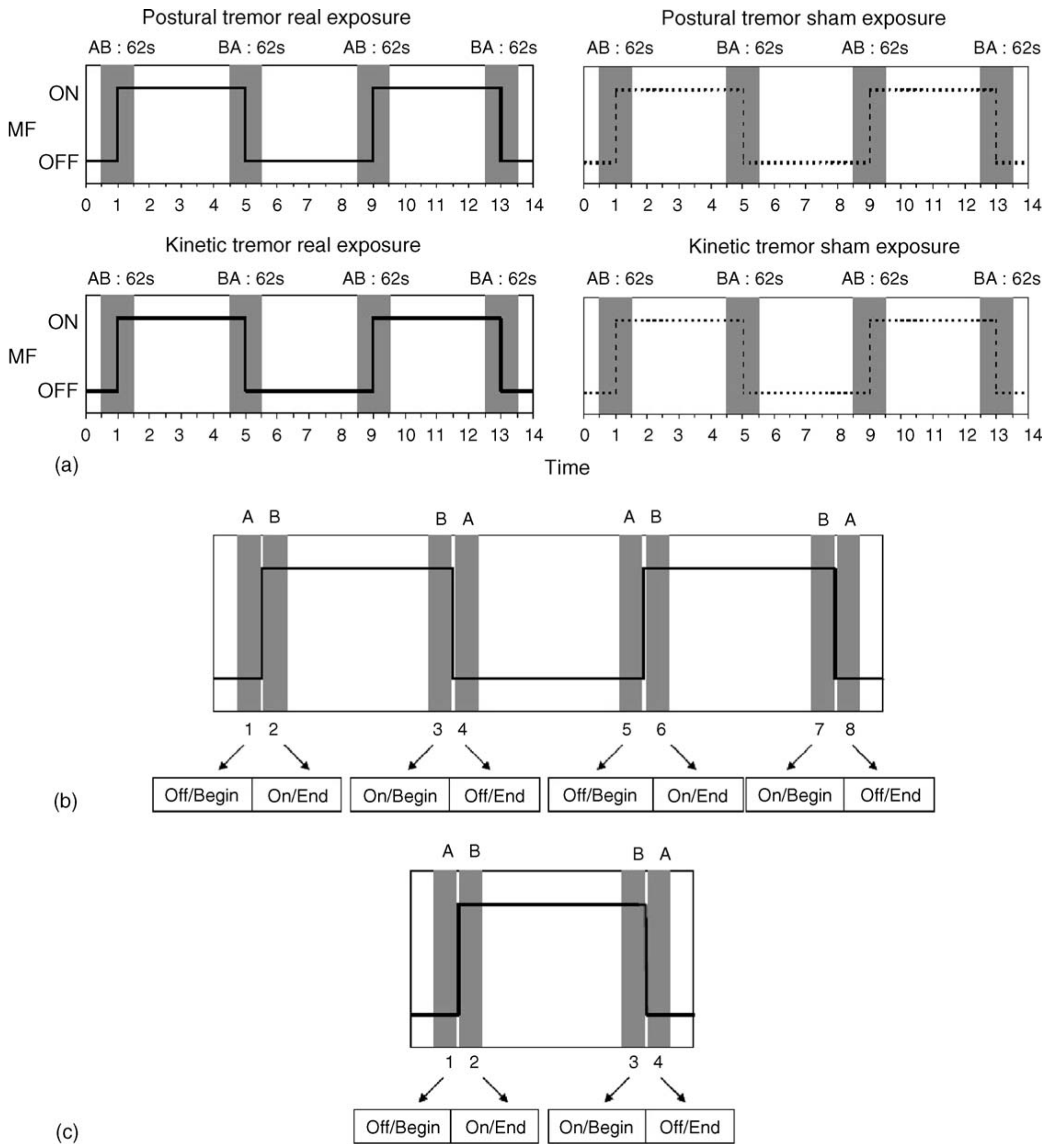


Fig. 2. (a) Illustration of the four sequences of an experimental session. The order of presentation of these sequences was counterbalanced. X-coordinates express time, vertical grey bands represent the 62 s recording periods and full lines show MF status ("off" when the line is down and "on" when the line is up). The dotted line represents the status of sham MF (i.e. its position if MF was present). (b) Only 20 s centered on a MF transition were kept in each recording and were composed of two parts of 10 s (before and after the MF transition). (c) Recordings 1, 2, 3, 4 and 5, 6, 7, 8 of Fig. 4a are respectively equivalent. Corresponding results were averaged for the second rANOVA in order to examine MF and order effects.

a result, the WT coefficients are influenced by local events while the Fourier coefficients are influenced by the function on its entire domain. This makes the wavelet coefficient a better measure of variance attributed to localized events or singularities, whatever its location in time and its size (i.e. its duration or period).

The base wavelet is a function that obeys some concrete mathematical conditions (continuity and differentiability; for details see [33]). In this work, we have chosen the popular, complex valued, Morlet wavelet ($\omega_0 = 5$) [29] enabling one to extract information about the amplitude and phase of the process being analyzed [34]. Flandrin in 1988 [35] proposed calling the result of a WT a scalogram or wavelet spectrum. Local maxima in the scalogram provide information about the frequency at which important features or a coherent event provides a significant contribution. This can happen in one of two ways: it can be due either to one feature with a large contribution or an association of several small features with lesser contributions. Either or both situations may be present in a signal.

The need to identify significant structures from a passive or noisy component of a signal is a common problem. The global wavelet spectrum has been quite useful for detecting the dominant scales or mode of vibration [36–38]. Variants of two techniques called “scale threshold partitioning” and “phase-plane threshold partitioning” [39] have been commonly employed to isolate the dominant modes of variation. In this work the threshold is chosen to be equal to a desired statistical confidence level. Indeed, Torrence and Compo in 1998 [34] have demonstrated that, each point in the wavelet power spectrum is statistically distributed as a $\chi^2$ (two degrees of freedom) about the background spectrum. Once the background spectrum is defined, the confidence level is computed as the product of the background spectrum (the power at each scale) by the desired significance level from the chi-square distribution. Modulus higher than the associated confidence level are said to be “statistically significant.” If the background spectrum is not known, as recommended by the later authors, the global wavelet spectrum (time-average of the wavelet spectrum) should be used as background. This is the method we chose and applied to our data.

The frequency range of physiological tremor generated by the central and peripheral nervous system is known to be between 8 and 12 Hz, and frequencies above 20 Hz are linked with mechanical properties of the index finger [11,15–17]. Thus, the frequency range of interest of postural tremor is between 2 and 20 Hz. Since these frequencies are exacerbated in velocity time series (see [40]), WT were conducted on velocity data in the 2–20 Hz frequency range, with the aim to detect transient effects that could correspond to short time amplitude or frequency modification of tremor induced by MF transitions. A local change in tremor amplitude could produce a local increase of the signal power in the considered frequency range and a change in the frequency organization of tremor could produce a modification of the frequency composition of the signal at the considered time.

## 3. Results

### 3.1. Wavelet analysis for individual subjects

Four transitions in real exposure sequences (two “off–on” and two “on–off”) and four transitions in sham exposure sequences were examined for each subject. Wavelet results varied across subjects. Tremor appeared generally organized in stationary frequency bands as for subject 33 (Fig. 3a). However, for some of the subjects the frequency content was not clearly distinguishable from the background (subject 26 for example, see Fig. 3b). For subject 33, the main component was clearly identified at 10 Hz (Fig. 3a) and modulated in amplitude. For all other subjects these main frequency components varied in thickness and in regularity over the 20 s recordings (example of subject 25, Fig. 3c). In general the results were consistent in the sense that frequency components were visible across the same type of transitions (e.g., “on–off”) within the same subject. However, the degree of amplitude modulation varied across trials independent of the presence or absence of MF.

Of particular interest in these frequency components was the 2–4 Hz band before and after the transitions, since previous analyses [20] indicated an increase in proportional power in this range when the MF was present. In general no obvious change in frequency distribution or modulation in amplitude or frequency was noted here on the individual graphics of the 24 subjects. Interestingly, a change occurring when the MF was turned “off” for subject 11 was noted for only one of the transitions (Fig. 3d), but no other systematic change was noted at the transition for all other subjects.

In four subjects, the presence of ballistic movement segments was visible on the wavelet plots and had a conic shape (examples of subjects 27 or 34 wavelet spectrum, respectively Fig. 3e and f) pointing to the time occurrence of a local singularity (short-term event of high amplitude) in the analyzed record.

### 3.2. Wavelet statistics

Because individual analysis of all scalograms (time-frequency maps, see Fig. 4) is a long and tedious process, we constructed a temporal index related to the local power of the analyzed tremor and so named “mean significant power” index (Fig. 4c). For each time of the time-frequency map, wavelet coefficients higher than statistical confidence level were summed (whatever their frequency), thus reducing information contained in 2D-maps into a new 1D-time profile. To further synthesize information, average powers 10 s before and 10 s after the MF transition were also computed, i.e. for the beginning and for the end of recordings (Fig. 4e). Then, these new parameters can be used in standard *t*-test and ANOVA statistical analysis to test the effect of MF transition (“off–on” or “on–off”) on postural tremor.

First, a *t*-test was used to compare the averaged “mean significant power” over all the MF “on” versus “off” conditions, only in the real exposure sequence. No statistical difference was found ($p > 0.05$, see Table 1). Next, a three-way ANOVA with repeated measures was conducted on “mean significant power” to identify differences between:

(1) real and sham exposure sequences (i.e. differences between the “mean significant power” computed on tremor time series recorded during the real exposure sequence and during the sham exposure sequence);
(2) MF “off” and “on” conditions (i.e. differences between “mean significant power” computed on tremor time series recorded during all the “on” and “off” conditions, during real but also during sham exposure sequences);

Table 1
Means and *t*-test between “on” and “off” conditions during real exposure

| | *t*-Test | | | |
|---|---|---|---|---|
| | Means | S.D. | *t* | *P* |
| MF OFF | 285.81 | 129.76 | 0.76 | 0.46 |
| MF ON | 282.65 | 123.89 | | |

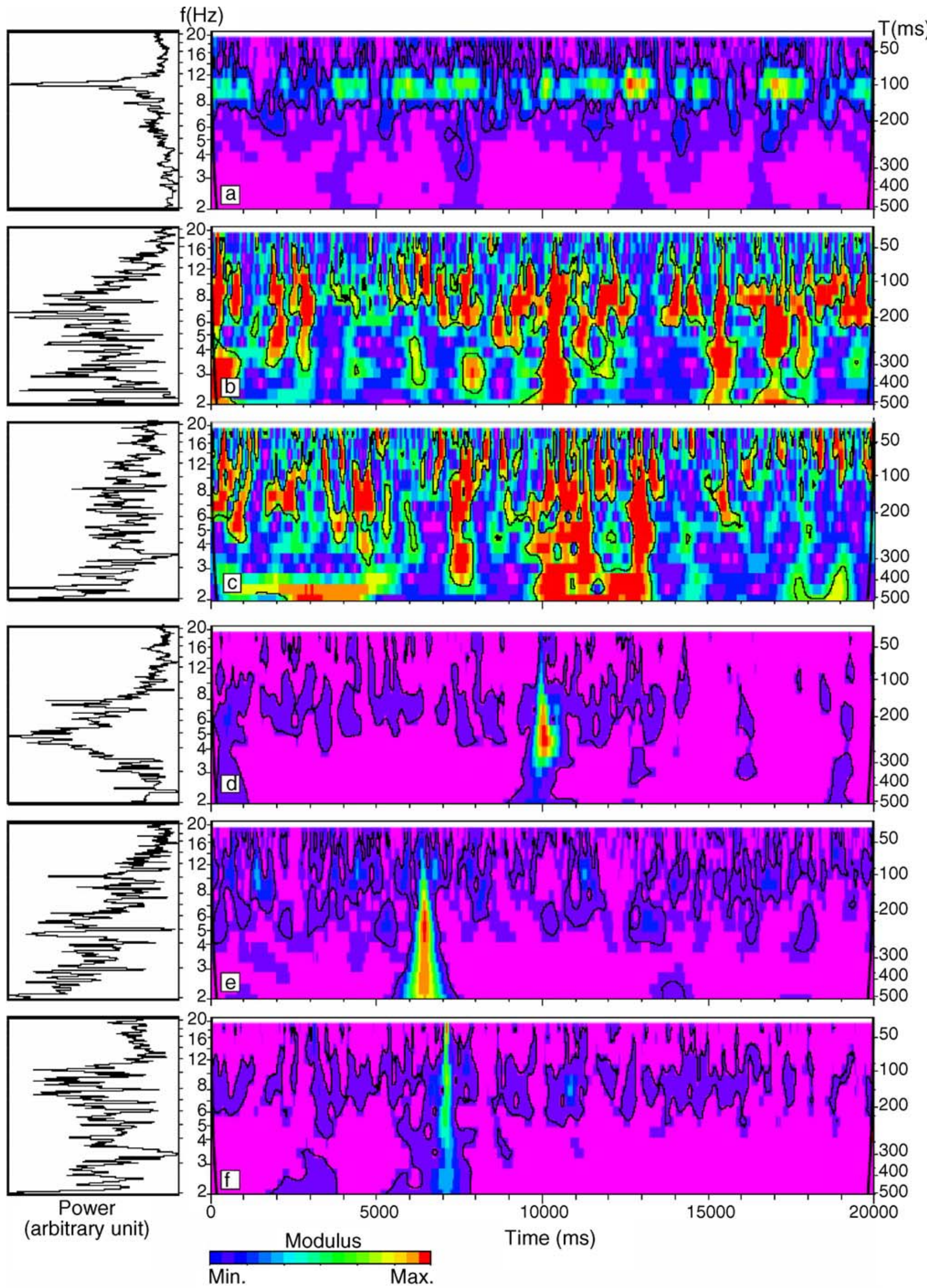


Fig. 3. Classical normalized Fourier spectrum (left) and wavelet analysis (modulus, right) of velocity tremor time series. Right vertical axis of the scale-time spectrum represent the period, *T*, of the locally detected cycles. Computations for period ranging from 48.5 to 512 ms (corresponding to frequencies between 1.95 and 20.6 Hz) have been performed in a dyadic scale. The middle vertical axis represents corresponding frequency scale. Thick vertical continuous black lines mark the limit where edge effects become predominant. Area inside the black lines are above the threshold value determined using the statistical test developed by Torrence and Compo [34]. (a) Subject 33 (transition "off–on") has a clear oscillation at around 10 Hz, with some fluctuation in amplitude. (b) In contrast, tremor frequencies of subject 26 (sham) are not clearly identified. (c) The frequency band of subject 25 (transition "off–on") varied in thickness and in regularity. There is a frequency band generally above 4 Hz but also a slow oscillation around 2 Hz, which disappears at the fifth second of recording and reappears briefly at the tenth second. (d) Subject 11 (transition "on–off") has a curious "twitch" in his tremor precisely localized at the time of a MF transition. (e) and (f) Subjects 27 (transition "on–off") and 34 (sham), respectively, present two other ballistic movements during the recordings.

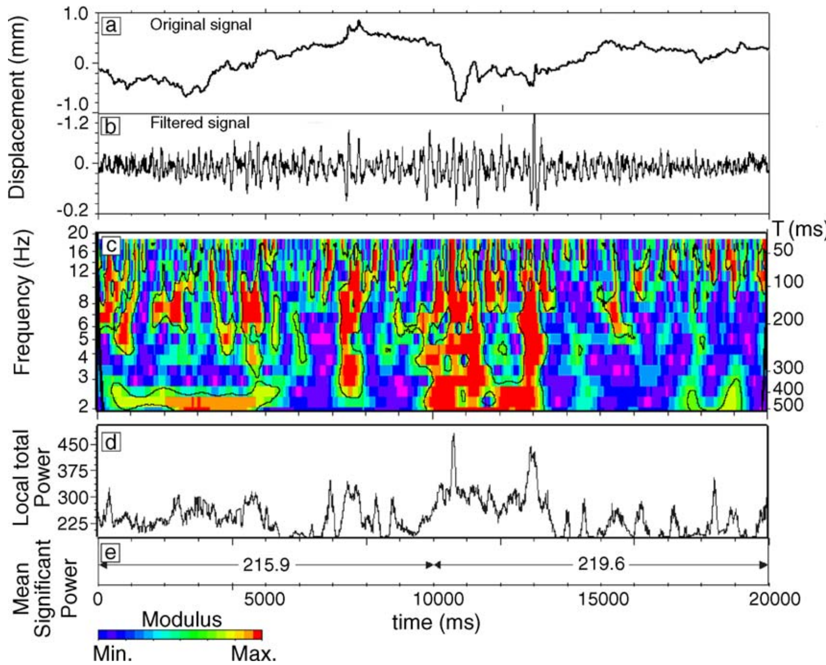


Fig. 4. Computation of the "mean significant power" on a recording of subject 25. (a) Original displacement recorded signal (frequencies above 20 Hz are filtered out). (b) The same signal, with frequencies below 2 Hz also filtered out. (c) Time-scale wavelet representation of the original velocity data obtained by derivation of the displacement record. (d) Local sum of the statistically significant wavelet power (sum of modulus higher than the threshold value determined using the statistical test developed by Torrence and Compo [34], represented by area inside the black lines). (e) Time-averaged power (i.e. "mean significant power") for the first and last 10 s of the recording. The "mean significant power" index obtained was then used for statistical analysis.

(3) beginning or end of a recording (i.e. differences between "mean significant power" computed on the first and on the last 10 s of tremor time series).

Results showed a significant time of recording effect ($F_{1,23} = 4.36$; $p < 0.05$; $\eta^2 = 0.18$): the "mean significant power" was significantly higher at the beginning than at the end of recordings, independently of the type of transition ("off–on" or "on–off", in real and sham exposure sequences). No difference was found neither between real and sham exposure sequences, nor between MF "on" and MF "off" conditions (results are detailed in Table 2). Interestingly, an interaction effect between time of recording and exposure sequence was found: Time of recording effect was more pronounced under real exposure sequence ($F_{1,23} = 5.88$; $p < 0.05$; $\eta^2 = 0.25$, see Fig. 5) than under sham exposure sequence. However, these results are subject to a high between-subject variability and have to be considered cautiously.

Heart rate and skin temperature were monitored during the experiment and were not affected by the experimental procedure.

Table 2
Results of the rANOVA 2 × 2 × 2 (exposure sequence (real vs. sham) × MF ("off" vs. "on") × time (first vs. last 10 s on recording))

| rANOVA 2 × 2 × 2 | | | |
|---|---|---|---|
| Effects | *F* | *P* | $\eta^2$ |
| Sequence (real/sham) | 0.44 | 0.51 | 0.01 |
| MF ("off"/"on") | 1.42 | 0.25 | 0.06 |
| Time of recording (beginning/end) | 4.36 | **0.05** | 0.18 |
| Sequence × MF | 0.00 | 0.97 | 0.00 |
| Sequence × time of recording | 5.88 | **0.02** | 0.25 |
| MF × time of recording | 0.45 | 0.51 | 0.01 |
| Sequence × MF × time of recording | 1.19 | 0.28 | 0.05 |

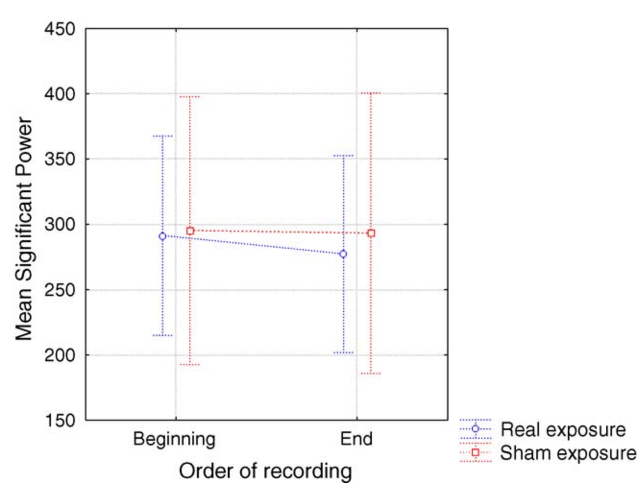


Fig. 5. Time of recording effect is not the same under real and under sham exposure sequences. The decrease of "mean significant power" between the beginning and the end of recordings is more pronounced under real than under sham exposure sequence.

## 4. Discussion

Wavelet analysis constitutes a valuable tool for analysis of tremor time series. Indeed, tremor is characterized by its amplitude, its frequency and its duration; and WT allows deciphering tremor fluctuations in terms of amplitude, frequency and duration and to extract corresponding simple parameters. For example, Fig. 3a clearly shows amplitude fluctuation of the 10 Hz tremor behavior of subject 33 which would not have been detected by a classical analysis. WT detected transient modifications in tremor recordings for subjects 11, 27, 34 (Fig. 3) and in a lower proportion in subject 10. However, the visual inspection of all wavelet spectra for all subjects did not reveal systematic behavior linked with MF transition. If such an instantaneous effect exists, it is too small to be detected with this approach.

Tremor is enhanced by fatigue or anxiety [41–46]. Moreover, it is known that behavioral relaxation training reduces tremor severity in patients with essential tremor or brain injury [47]. Interestingly, just following the present experimentation, subjects were asked if they found the session rather stressful or rather relaxing and 21 over 24 subjects answered relaxing. They said that it was essentially linked with the absence of external auditory stimuli (due to the earplugs and the anti-noise helmet). A few of them underlined that during recording, they were more centered on themselves (they heard their heart pulses for example). In this perspective, even if it has never been noticed before, the decrease of the "mean significant power" of tremor (consistent with the decrease found in amplitude in our previous work) should not be due to fatigue but rather to a progressive relaxation of the subject during the minute of recording. Interestingly, Cook et al. (2004), who showed an effect of a pulsed 200 $\mu$T MF on EEG alpha activity [8], underlined the link between resting posterior alpha activity and the state of relaxed wakefulness [48]. Still, though our effect may be due to a progressive relaxation induced by the minute of postural tremor recording, it may also be exacerbated by the auditory input privation imposed by our protocol.

Several studies have shown effects of ELF MF on human electrophysiological parameters [8,22,23,49–53] but there is no consensus on the direction of the observed effects. Therefore, if a link exists between neuronal excitability and physiological tremor, and if the MF used in this study is strong enough to modify its excitability, it should be detected in physiological tremor recordings. Our previous work did not show such an effect between conditions, but it did not explore tremor at the transition time. In this work, the WT was used with two main objectives: (1) visually detecting systematic behavior in tremor time series at the transition time and (2) comparing subjects' behavior before and after MF transitions ("off–on" and "on–off") in the time/frequency space. Consistent with our previous work [20], no instantaneous MF effect was found.

It has been shown using transcranial magnetic stimulation (TMS, a high intensity magnetic stimulation of the cerebral cortex) that central nervous system (CNS) excitability can be increased or decreased depending on the latency period separating stimuli [54]. Moreover, voluntary contraction of hand muscles increases CNS excitability and a lower level of TMS is then needed to produce a minimal and reliable motor response. Valls-Sole et al. (1992) showed that a low-intensity TMS can inhibit motor pathway excitability (with an inter-stimulus interval of 5–40 ms) [55]. Furthermore, it has been shown that TMS can reset pathological tremor in patients with familial essential tremor and with Parkinson's disease [56]. However, these studies use MF several orders of magnitude larger than the MF used in this study and there is no evidence that the same brain mechanisms are involved. Nevertheless, given all results and given the potential link between ELF MF exposure and relaxation, one can speculate that the exposure to an ELF MF could result, in some way, in a tremor size reduction. It is therefore possible that the observed relaxing effect masks a subtle MF effect. Results of the rANOVA confirm this possibility. Indeed, they show that the relaxing effect is more pronounced under real exposure than under sham exposure. However, given the wide between-subject variability and the subtlety of the difference, this effect should be interpreted as a significant tendency, meaning that MF effect could be delayed and would persist after switching it off. Cook et al. (2004) showed that the effect of a 200 $\mu$T pulsed MF on human EEG disappears only after a delay of between 3 and 7 min [8]. If the same delays are involved here, it could explain the difference between real and sham exposure: in a real exposure sequence, the MF effect would persist when MF is turned "off" and could affect the following "off" conditions (before it is turned "on" again). From this perspective, we have to take into account that sham exposure sequences could have been "contaminated" by the preceding real exposure sequences. This "cross-over" effect underlined in other studies (see [8] for example) constitutes a limit of our protocol and different exposure sequences should be planned on separate days in the future. However, the effect of the order of presentation of the sequences has been evaluated for each subject in another work [21] and no influence has been found on the results.

Prato et al. (2001) have shown that MF effects on human postural sway can be modulated by light intensity [25]. Thus, the fact that light intensity has not been controlled in this work could have introduced a confounding factor that possibly hides the MF effect. However, the results of Prato et al. (2001) showed an impact of light intensity on human postural sway only during eyes closed and not during eyes open conditions [25]. The present study was realized exclusively with eyes open; therefore, the variations of light intensity between days should not have interfered with the effect of the MF. Moreover, the analysis of the individual results developed elsewhere [21] does not show any impact of the variability of daylight intensity.

This work shows an effect of a global exposure to a 1000 μT, 50 Hz MF centered at the level of the head on human postural tremor. This effect is characterized by a decrease in tremor average power that could be the consequence of a state of relaxation exacerbated by ELF MF exposure. Therefore, ELF MF exposure detection seems possible through the analysis of human postural tremor. However, further analyses are needed to reproduce this result and to verify if this effect persists without the auditory deprivation induced by the experimental protocol used.

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