

# The isometric muscle contraction tasks or repetitive movements to evaluate the effects of fatigue. A systematic review

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## Summary

Fatigue has been defined as a phenomenon related to the time of decrease of the maximum capacity of generation of force, expressing itself, generally, as a deterioration in the maximum voluntary contraction (CMV). The appearance of fatigue in skeletal muscle during an effort has long been of interest to physiologists, especially because fatigue is a limiting factor in athletic performance or in the performance of any task. The aim of the article is to analyze the literature and provide a systematic review on fatigue induced by muscle contraction tasks, caused by isometric contractions or by finger tapping. To this end, an investigation was carried out based on the PRISMA methodology (Articles of preferred reports for systematic reviews and meta-analyses). Conducting a search of articles in the PubMed, Medline, Science Direct and Google Scholar databases, between the months of June and November of 2017 after the year 2000. Of the 315 studies initially identified, only 12 complied with the established selection criteria. The methodological variability of the different studies allows to observe how through the tapping tasks (repetitive movements of fingers), or through isometric contraction tasks, it is possible to determine the different parameters of fatigue that are evaluated in each study, being a very used to address that topic. Muscle fatigue has been predominantly studied when induced by isometric tasks, with a greater number of investigations using this type of methodology, since, although finger tapping is a reliable procedure to evaluate the underlying neurophysiological mechanisms of fatigue, it has been explored.

**Key words:**  
Isometric contraction.  
Finger tapping. Fatigue.  
Contractile force.

## Las tareas de contracción muscular isométricas o de movimientos repetitivos para evaluar los efectos de la fatiga. Una revisión sistemática

### Resumen

La fatiga es definida como un fenómeno relacionado con el tiempo de disminución de la capacidad máxima de generación de fuerza, expresándose, como un deterioro en la contracción máxima voluntaria (CMV). La aparición de la fatiga en el músculo esquelético durante un esfuerzo ha sido de interés para los fisiólogos, especialmente porque la fatiga es un factor limitante, tanto en el rendimiento deportivo como en la realización de cualquier tarea. El objetivo del artículo es analizar la literatura y proporcionar una revisión sistemática sobre la fatiga inducida por tareas de contracción muscular, provocadas por contracciones isométricas o mediante tapping de dedos. Para ello se realizó una investigación basada en la metodología PRISMA (Artículos de informes preferidos para revisiones sistemáticas y metanálisis). Llevando a cabo una búsqueda de artículos en las bases de datos PubMed, Medline, Science Direct y Google Scholar, entre los meses de junio y noviembre de 2017 con fecha posterior al año 2000. De los 315 estudios identificados inicialmente, sólo 12 cumplieron con los criterios de selección establecidos. La variabilidad metodológica de los distintos estudios permite observar como a través de las tareas de tapping (movimientos repetitivos de dedos), o mediante tareas de contracción isométrica se pueden determinar los distintos parámetros de la fatiga que se evalúan en cada estudio, siendo un instrumento muy utilizado para abordar dicho tema. La fatiga muscular se ha estudiado predominantemente cuando es inducida por tareas isométricas, habiendo un mayor número de investigaciones que utilizan este tipo de metodología, ya que, aunque el tapping de dedos sea un procedimiento fiable para evaluar los mecanismos neurofisiológicos subyacentes de la fatiga, apenas se ha explorado.

**Palabras clave:**  
Contracción isométrica. Tapping de dedos. Fatiga. Fuerza contráctil.

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## Introduction

The onset of skeletal muscle fatigue during exertion has long been a source of interest to physiologists, particularly because fatigue is a limiting factor in sport performance or for carrying out any task<sup>1</sup>. Fatigue has been defined as a phenomenon related to the decrease over time of the maximal ability to produce force<sup>2</sup>, generally expressed as a deterioration in the maximal voluntary contraction (MVC). According to the force-fatigability relationship<sup>3</sup>, the greater the force exerted by a muscle, the faster it will fatigue and reach the point of failure (inability to maintain the required force).

The voluntary contraction of a muscle to produce force or movement, according to Taylor *et al.*<sup>4</sup>, involves a series of events that start in the brain and end in the muscle. The processes leading to muscle fatigue commence when a person makes repetitive or sustained contractions of the muscle. Therefore, muscle fatigue can be defined as an exercise-induced loss of ability to produce force with a muscle or muscle group<sup>5</sup>. This condition is temporary and reversible with rest, except for chronic fatigue pathologies. As a chronic symptom, fatigue is a well-known manifestation of a series of somatic disorders, including cancer, multiple sclerosis (MS), Parkinson's disease (PD) and cerebrovascular disorders.

The term fatigue is used both to describe the condition of a specific localised group of muscles and to refer to a situation in which tiredness is generalised and affects the entire body. Frequently, fatigue is not located in a group of muscles or in an individual physiological process within the muscle, instead, it involves a number of processes acting in parallel, including the muscle and the structures continuing through the entire neural axis<sup>5</sup>. Due to its multifactorial nature, the mechanisms responsible for fatigue are still imprecise. Consideration is given to muscle level factors, causing neuromuscular or peripheral fatigue, and factors above the neuromuscular junction, generating central fatigue<sup>6</sup>.

Muscle fatigue has primarily been studied when it is induced by isometric tasks (iso), however the underlying neuropsychological mechanisms of fatigue during rapid repetitive movements known as finger tapping have barely been explored, while the tapping test is a reliable procedure used throughout the world to evaluate the physiological and pathological mechanisms of repetitive movements<sup>7</sup>.

It has been demonstrated how, with voluntary contraction, the motor-evoked potential (MEP) increased in size in comparison to the evoked motor potentials obtained from the relaxed muscles, and how this reflected greater cortical and spinal excitability<sup>8,9</sup>. Fatiguing exercise can reduce cortical excitability, as already demonstrated by Brasil-Neto *et al.*<sup>10</sup> where, immediately after the subjectively fatiguing exercise, the MEP amplitude increased in size while the silent period increased in duration with muscle fatigue.

It is widely accepted that there is no single cause for fatigue, the physiological mechanisms behind the reduction in the ability to produce force, prohibiting the indefinite performance of tasks, are specific to the task demands (in other words, the contraction intensity, duration, mode, muscle group, joint angle, limb posture and stabilisation). In general,

it has been shown that the failure of the nervous system to maintain sufficient activation of the muscle is an important contributor to task failure in sustained submaximal contractions in comparison to maximal contractions<sup>11</sup>.

To our knowledge, very few studies have reviewed the different methods of inducing fatigue and what this involves. Therefore, the purpose of this study is to analyse the literature and to provide a systematic review of fatigue induced by muscular contraction tasks, caused by isometric contractions or finger tapping.

## Methodology

A theoretical analysis was conducted with a systematic review of the literature available on intervention studies made through isometric contractions or finger tapping, in accordance with the PRISMA Preferred Reporting Items for Systematic Reviews and Meta-Analyses methodology (Figure 1).

The articles in this review were obtained through a search in the electronic databases of PubMed, Medline, Science Direct and Google Scholar. The descriptor terms or key words for the search were as follows: muscle fatigue, finger tapping, muscle contraction and repetitive movements. For the correct use of terminology, we consulted the descriptor terms of the Medical Subject Headings, making a review of peer-reviewed journal articles between the months of June and November 2017, in English, Spanish and Portuguese, dated later than the year 2000.

The following method was used for the bibliographic search:

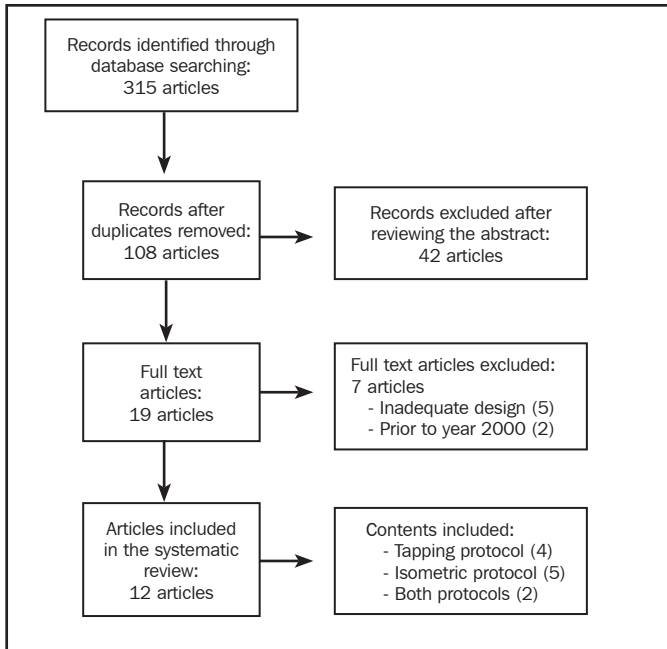
- Studies analysing fatigue by isometric or isotonic contractions, making it possible to extract the most relevant information from each investigation.
- Synthesis of information, making it possible to sort and combine the information obtained, and to make a comparative analysis between studies on contractions through Tapping or maximal voluntary contraction (MVC).
- Once the search had been completed, we then determined which articles were to be included in the review. To do so, it was necessary to consider the value and relevance of the subject studied, as well as to analyse the applicability of the results to the subject of study.

Articles written in English, Spanish or Portuguese were included if the protocols were based on tasks in which isometric contraction or finger tapping tasks were used to induce fatigue.

Studies were excluded if the methodology or design was considered not to comply with the above mentioned protocols, if they were summaries of conferences, papers or news items, or if they were prior to the year 2000, in order to base the review on up-to-date investigations.

The initial search process identified 315 articles, of which 207 duplicate articles were eliminated. The remaining 108 articles were selected in order to determine their relevance, based on their title and abstract. This resulted in the elimination of a further 66 studies, leaving a total of 42 studies, examining the complete text of 19 of these. Finally, 12 texts

**Figure 1. Flow diagram of the PRISMA methodology showing the identification, screening and selection of relevant studies for this systematic review.**



met the established selection criteria, following the critical reading of the entire document (Figure 1).

The validity of the articles selected was given by the level of evidence demonstrated, the recommendations of the article and the applicability to our context.

## Results

The methodological variability of the different studies is explained below. These studies discuss how, through fatigue induced by repetitive finger tapping tasks or by isometric contraction tasks, it is possible to determine the different fatigue parameters evaluated in each study.

For this purpose, we started by looking at the studies based on the use of contraction tasks (Table 1), where Klass *et al.*<sup>9</sup> compared the selected inputs with the groups of motor neurons of the elbow flexor muscles during the performance of force and position tasks. The force task consisted in performing a fatiguing contraction at 20% of MVC for as long as possible, ending when it was not possible to maintain the torque level required during 5-10 s. The position task consisted in maintaining the elbow joint at a right angle while supporting an inertial load equivalent to 20% of the MVC, sustaining this position for as long as possible and ending when the elbow angle declined by 10° from the target during 5-10 s. Both tasks required a sustained isometric contract with the elbow flexor muscles.

Williams *et al.*<sup>11</sup> compared the facilitatory and inhibitory supraspinal adjustments and the voluntary drive of the motor cortex for force-

matching and position-matching tasks. Subjects needed to perform two fatiguing tasks. One task consisted in sustaining a force equivalent to 15% MVC for as long as possible, pulling against a force transducer tied to a chair. The length of the transducer prevented the elbow from flexing more than 90°. The second test consisted in maintaining, until task failure, the position of the elbow joint at 90°, supporting a free weight equivalent to 15% of the MVC force.

Butler *et al.*<sup>14</sup> performed a sustained maximal voluntary effort (MVC) of the right elbow flexors for 120 sec to determine whether the motoneurons were inhibited during a maximal isometric contraction. The elbow was flexed to 90° strapped to an isometric myograph. Before the test contraction, a series of brief MVCs were performed (for 2-3 sec.) at 1 min intervals. Following the test contraction, some brief MVCs were performed.

In order to compare the behaviour of short-latency reflexes (H reflex) and long-latency reflexes (LLR), Duchateau *et al.*<sup>15</sup> conducted 3 sessions. A fatiguing contraction performed at 25 % MVC and sustained until the endurance limit. In the second session, the subject performed an intermittent contraction (6 s contraction, 4 s rest) at 25% MVC for the same duration as the sustained contraction at 25 % MVC. For the third session, the subject performed a contraction sustained at 50% MVC until the endurance limit. The sustained contractions (25 and 50% MVC) ended when the subject was unable to maintain the required level of force during 5 s.

By five isometric maximal voluntary flexions of the elbow (1, 2 s) separated by one minutes rests, Taylor, *et al.*<sup>16</sup> examined the development of the supraspinal component of central fatigue. The patterns used were 5 s at 50% of MVC and 5 s rest. 12, 15 s contractions at 60% of MVC and 10 s rest. 12, 15 s contractions at 75% of MVC and 5 s rest. And 6, 30 s contractions at 86% of MVC and 5 s rest. Finally, subjects performed a series of brief MVCs at 15 s, 30 s, and 1, 2, and 3 min after the series of fatiguing contractions. During each brief contraction, a single transcranial magnetic stimulus was given.

Finally, Maluf and Enoka<sup>17</sup> compared the physiological adjustments that occur when two similar fatiguing contractions are performed to failure. To do so, 2 different tasks were performed. In the force task, the limb was attached to a restraint and the subject was required to sustain a constant force (15–20% of maximum) for as long as possible. In the other task, the position task, the subject supported an inertial load that was equivalent to the force exerted during the force task and was required to maintain a constant joint angle for as long as possible. The criterion for task failure was an inability to sustain the target force or position for at least 5 s.

Based on the use of tapping tasks (Table 2), Arias *et al.*<sup>7</sup> evaluated cortico-spinal fatigue between three groups; one group of subjects with Parkinson's, one group of elderly subjects and a group of young people.. The subjects were seated comfortably with their forearms resting on a table, their elbows bent at 90°. They were asked to perform tapping tasks with their index finger by flexing-extending the metacarpophalangeal joint. Two modes were included: tapping tasks (FT) at their fastest rate

Table 1. Articles related to the use of isometric contraction tasks.

Author	Sample	Objective	Results
Klass <i>et al.</i> 2008	11 subjects (6 male and 5 female) aged between 22 and 41 years ( $29.4 \pm 6.0$ years)	Compare the selected inputs with the groups of motor neurons of the elbow flexor muscles during force and position tasks. The comparisons involve MEP in response to the TMS and the Hoffmann reflex induced by the electrical stimulation of the brachial plexus at Erb's point.	The study revealed how the MVC mean torque before the fatiguing contraction was similar for the force session and the position task session. The aEMG for the biceps brachii during the MVC of the elbow flexor decreased immediately after the fatiguing contraction in the force and position tasks.
Williams, Hoffman, and Clark. 2014	10 healthy right-handed subjects (5 male, 5 female), mean age of 24 years. The subjects identified themselves as highly active (n=2, 1 male, and 1 female,) moderately active (n=5, 3 male, 2 female), or low active (n=3, 1 male, 2 female).	Compare the supraspinal, facilitatory and inhibitory adjustments and the voluntary drive of the motor cortex, measured with TMS, in relation to force-matching and position-matching tasks.	The study showed how the level of corticospinal excitability (MEP and SP induced MEP) increased throughout the performance of the fatiguing task while the CMEP in SP decreased. Furthermore, the intracortical inhibition ratio within the motor cortex either decreased or was maintained during the performance of the fatiguing task.
Butler, Taylor and Gandevia. 2003	2 groups: Experimental with 8 subjects (5 male and 3 female) who were studied on two occasions. And Control, with 8 subjects (4 male and 4 female) 3 of the subjects performed both the main and control experiments. The subjects were healthy and ranged in age from 30 to 58 years	To determine whether motoneurons were inhibited during a sustained fatiguing contraction of the elbow flexor muscles and whether this inhibition was caused by the discharge of group III and IV muscle afferents.	During the sustained MVC, there were changes in the size of the responses in brachioradialis and biceps brachii produced both by corticospinal stimulation and brachial plexus stimulation, revealing a decrease in the size of the muscle response to corticospinal tract stimulation during fatigue. Decreasing the excitability of motoneurons, contributing to the decline of the discharge rate of motor units and the development of central fatigue that occurs with sustained MVCs.
Duchateau <i>et al.</i> 2002	13 healthy volunteers, 3 female and 10 male, aged 21 to 46 years.	To compare the behaviour of the short-latency (H reflex) and long-latency (LLR) reflexes in the APB during contractions sustained at 25 % and 50 % MVC and during sustained and intermittent contractions at 25 % MVC.	Both showed a reduction in absolute amplitude, with no significant change in the H reflex or the LLR amplitude. The MVC force declined at the end of the sustained 25% MVC and 50% MVC tests. The averaged EMG associated with the MVC was reduced after the sustained contractions at 25 % and 50 % MVC but not for the intermittent contractions.
Taylor <i>et al.</i> 2000	9 healthy volunteers, 5 male and 4 female, aged 25 to 46 years.	Examine whether the development of the supraspinal component of central fatigue was similar during exercise protocols with differing levels of activity.	They demonstrated how the silent period lengthened, and the MEP increased in size. At the end of the fatiguing protocol after a total 3 minutes of contraction, the prolongation of the silent period varied between 20 ms with the 50% duty cycle and 0.75 ms with the 30 s MVC and 5-s rest.
Maluf and Enoka. 2005	16 subjects, 8 male and 8 female, aged $27 \pm 4$ years.	To compare the physiological adjustments that occur when two similar fatiguing contractions are performed to failure, it is possible to identify mechanisms that limit the duration of the more difficult task.	It was observed how the time to task failure was consistently less for the position task ( $702 \pm 582$ s) compared with the force task (1.402-768s). However, the amount of fatigue experienced by the subjects during both tasks was similar, as indicated by comparable ratings of perceived exertion at failure and the reductions of 28–35% in MVC force immediately after each fatiguing contraction.

(FAST) and tapping at their comfortable rate (COMFORT). The complete protocol consisted in 3 series of 50 cycles at COMFORT and 3 series of 50 cycles at FAST. This was repeated twice, with a one week interval. Recordings were made by an electronic system which included a metal plate and a metal ring adapted to the finger.

Anwar *et al.*<sup>12</sup> used tapping tasks that included simple finger tapping tasks (FT), simple finger sequences (SFS) and complex finger sequen-

ces (CFS) to check the connectivity of the sensorimotor network. By conducting a block design whereby the subjects performed finger movement tasks for 30 s followed by 30 s of rest. Ten complete blocks were performed for each finger movement task, 10 minutes per task. With 2 minutes' rest between each movement task.

The investigation of Lutz *et al.*<sup>18</sup> consisted in evaluating the hand used (dominant vs non-dominant) to determine the amount of the

**Table 2. Articles related to the use of Tapping tasks.**

Author	Sample	Objective	Results
Arias <i>et al.</i> 2012	3 different groups (17 subjects with Parkinson's average age of 69.47 years, 20 elderly healthy controls average age of 70.55 years, and 21 young healthy control subjects, average age of 23.90 years).	To evaluate the validity of the finger tapping test (FT) to detect alterations in rhythm formation.	The results demonstrated how the finger tapping of the group of young people was significantly faster than the Parkinson's and elderly groups. While no sign of fatigue appeared in the Parkinson's and elderly groups, the group of young people showed an evident decrease in the tapping frequency.
Anwar <i>et al.</i> 2016	9 healthy subjects, 5 female and 4 male with an average age of 27 years (range 21-38 years)	To apply the Granger causality analysis to the EEG, fMRI and fNIRS signals in order to determine the effective connectivity of contralateral cortico-cortical sensorimotor network during simple and complex finger movement tasks.	The tapping tasks were associated with increased activity in the SMC, PMC and DLPFC.
Lutz <i>et al.</i> 2004	9 healthy subjects (3 female, 6 male) 4 right-handed and 5 left-handed aged from 22 to 34 years.	To evaluate the extent to which the hand used (dominant vs. sub-dominant) determines the amount of the pattern of activation in the contralateral primary motor cortex, measured through magnetic resonance, during FT at own rate and at maximum speed.	There was a greater increase in the cortical activations of the right motor cortex, when right-handed subjects tapped with their left hand in comparison with the opposite hand. Differentiating the maximum tapping rate between hands, with shorter inter-tapping intervals for the dominant hand (130 to 180 ms) than for the non-dominant hand (160 and 200 ms).
Teo <i>et al.</i> 2011	10 healthy right-handed subjects, 5 male and 5 female, aged 21-32 years.	To investigate the changes in the ECM and SICI following a 10 second MVR test of the index finger, comparing self-paced and external movements. In order to determine whether the central effects were specific to the MVR task, a comparison was made with kinetically sustainable slower movements.	The results show how the performance of an MVC rhythmic tapping task rapidly decreases and is followed by a decline in the ECM. A similar post-exercise depression also occurs when the task is performed at slower, sustainable rates. With each of these tasks, the reduction in excitability is accompanied by an increase in the short interval intracortical inhibition (SICI) which is greater following the slower tasks than the MVR task.

**Table 3. Articles related to the use of both tasks (contraction and tapping).**

Author	Sample	Objective	Results
Arias <i>et al.</i> 2015	2 groups. The TMS group with nine right-handed healthy subjects (eight males and one female, with an age range of 22 to 38 years), and the CMS group with 12 right-handed healthy subjects, all males with an age range of 18 to 41 years.	To observe the differences in the motor-evoked potential and the changes in excitability of the cortical and spinal circuits, between the maximal FT and ISO tasks.	It was seen how the force decreased at the end of the session for both tasks. For the FT task, the maximal voluntary contraction force decreased right at the end. While, for the ISO task, we observed an accumulation of fatigue expressed in the decrease in MVC force.
Rodrigues, Mastaglia, and Thickbroom. 2009	10 healthy volunteers, 4 male and 6 female, aged 25 to -51 years.	To investigate the change in the movement rate and amplitude in healthy subjects performing repetitive finger flexion-extension in a maximal voluntary movement or tapping task.	The maximum rate of movement was maintained for a few seconds, showing a constant decline throughout the task, while the amplitude of movement remained unchanged. The subjects were unable to sustain the tapping at a maximum rate for more than a few seconds, leading to a constant decline in frequency with no change in amplitude. There were no changes to the isometric MVC force following the MVR task, with no loss of the force generation capacity.

pattern of activation in the contralateral primary motor cortex. Measured through magnetic resonance, during FT at own rate and at maximum speed. An arrow to the right or left indicated the hand to be used for the tapping, the colour of the arrow indicated the tapping rate (green, own rate and red, maximum rate). 4 sessions divided into 6, 20 s tapping blocks, followed by a 20 s rest.

To finalise, Teo *et al.*<sup>19</sup> investigated the changes occurring in corticomotor excitability (CME) and short interval cortical inhibition (SICI) when performing finger tapping. Participants performed three series of 10-second cyclic flexion-extension movements (starting with the neutral position in relation to the metacarpophalangeal joint (MCP) at different rates.

With regard to the investigations using both action protocols (Table 3), it can be observed how in the investigation conducted by Arias *et al.*<sup>13</sup> the subjects underwent two sessions in order to observe the differences in the motor-evoked potential and the changes in excitability of the cortical and spinal circuits, between the maximal FT and isometric tasks. One session in which the subjects performed tapping with their index finger on a metal plate mounted on a force sensor. And, in the second session, a continuous isometric test, also pressing the goniometer.

Finally, Rodrigues *et al.*<sup>20</sup> investigated the change in amplitude and in the movement rate when performing finger tapping. The maximal voluntary contraction (MVC) force was measured through a force transducer, performing a maximal voluntary flexion of the finger for 3 s, brief pause and then a maximum voluntary extension of the finger for 3 s. In order to obtain the force generating capacity of the index finger flexors and extensors, the rates of the ballistic flexion and extension movements were measured. For the task of the repetitive voluntary movement (RVM), continuous flexion-extension movements were performed with the index finger, as quickly as possible, maintaining the maximum rate for a period of 20 s.

## Discussion

The purpose of this investigation was to provide a systematic review of fatigue induced by muscle contraction tasks, triggered by isometric contractions or by finger tapping.

The studies using isometric contractions to induce muscle fatigue<sup>9,11,14-17</sup> have differing objectives, since this type of methodology permits a wide range of investigations. Through the application of isometric contractions to compare force tasks (performing a fatiguing contraction by maintaining constant force over a period of time) and position tasks (maintaining the position of a joint for as long as possible while supporting an inertial load) it has been possible to compare the selected inputs with the groups of motor neurons of the elbow flexor muscles<sup>9</sup>. As well as the physiological adjustments that occur when two similar fatiguing contractions are performed to failure, it is possible to identify mechanisms that limit the duration of the more difficult task<sup>17</sup>. In addition to defining the contribution of the mechanisms provoking supraspinal failure of the task during sustained submaximal contractions, comparing the specific differences of the task in the adjustments in cortical and spinal excitability<sup>11</sup>.

Studies based on the application of maximal voluntary contractions also have a wide scope of action, such as checking motoneuronal excitability<sup>14</sup>. A comparison of the behaviour of short-latency reflexes (H reflex) and long-latency reflexes (LLR)<sup>15</sup>. The study by Taylor *et al.*<sup>16</sup> examined whether the development of the supraspinal component of central fatigue was similar during four, three-minute exercise protocols with differing levels of activity (5 s MVC, 5 s recovery). 15 s MVC, 5 s recovery. 15 s MVC, 10 s recovery and 30 s MVC, 5 s recovery), demonstrating a supraspinal component of central fatigue produced by a series of intermittent MVCs.

The finger tapping test is a basic tool for evaluating rhythmic movement patterns. It is commonly used in clinical assessments and as part of investigation protocols, including brain imaging studies<sup>21,22</sup> and neurophysiological examinations<sup>23,24</sup>. With regard to the studies that conducted tapping tasks to induce fatigue<sup>7,12,18,19</sup>, it has been possible to examine the validity of this protocol by two different modes, Fast and Comfort, for different groups (young, elderly and persons with Parkinson's disease) and to re-evaluate some methodological aspects of its use<sup>7</sup>.

This type of methodology has also been used to determine the effective connectivity of the contralateral cortico-cortical sensorimotor network during simple and complex finger movement tasks, by applying the Granger causality analysis to the EEG, fMRI and fNIRS signals. Lutz *et al.*<sup>18</sup> aimed to demonstrate the extent to which the hand used (dominant vs non-dominant) determines the amount of the pattern of activation in the contralateral primary motor cortex at maximum rate and comfort rate, given that a number of brain imaging studies consistently demonstrated increased cortical activation (indexed by an increase in haemodynamic responses) as a function of the increase in the finger tapping frequency in the primary motor cortex, the cerebellum and partly in other motor areas<sup>25,26</sup>.

This type of protocol was also used to investigate changes in corticomotor excitability and the short-interval cortical inhibition following a 10 s tapping task of the index finger, comparing self-paced and external movements. In order to determine whether the central effects were specific to the task, a comparison was made with kinetically sustainable slower movements.

Finally, there were also studies that included the use of isometric contraction tasks and also finger tapping in their protocol to induce fatigue. Such as the study by Arias *et al.*<sup>13</sup> which compared the neurophysiological signs of fatigue induced by tapping with those induced by isometric contraction tasks, in order to analyse the underlying neurophysiological mechanisms of fatigue during fast repetitive movements (tapping). In order to thereby determine the contribution of some spinal and supraspinal motor circuits to the production of fatigue during short-lasting repetitive movements (finger touching), if performed at the fastest possible rate. Furthermore, studies of the maximum isometric or isotonic movements of the finger have shown a possible relation between speed and amplitude<sup>27</sup>. For this reason, Rodrigues *et al.*<sup>20</sup> aimed to investigate the change in the rate of movement and amplitude in healthy subjects performing a repetitive finger flexion-extension task at maximal voluntary rate.

## Conclusion

This systematic review was addressed in order to provide information about fatigue induced by muscle contraction tasks, observing how the majority of investigations use isometric contractions, in comparison to those using the finger tapping methodology.

Muscle fatigue has predominantly been studied when it is induced by isometric tasks (iso), however the underlying neuropsychological mechanisms during rapid repetitive finger tapping have scarcely been considered, while the tapping test is a reliable procedure to evaluate repetitive physiological and pathological mechanisms.

The methodology search considered in this review (isometric contractions and tapping) makes it possible to address the subject of fatigue, particularly when investigating how fatigue can affect the performance of individuals, as well as in the daily lives of patients suffering from pathologies in which fatigue is a chronic symptom.

The performance of maximal isometric contractions leads to the progressive failure of voluntary activation, causing subjects to be unable to fully activate the muscles, thereby demonstrating the appearance of central fatigue.

Intermittent fatiguing contractions, as already demonstrated for sustained voluntary contractions, cause changes in the responses of the muscle electromyography (EMG) to transcranial magnetic stimulation, extending the silent period and increasing the size of the MEP more quickly, recovering more slowly than the extension of the silent period.

The tapping task produces a constant decrease in the speed at which the movement is made, exhibiting similar effects on excitability and inhibition, both after exercise and after an fatiguing isometric MVC task, causing decreased performance due to the fact that it is not possible to sustain the demands in the motor control.

When addressing different objectives, the variety provided by the use of this type of methodology makes it a highly utilised instrument by investigators considering the wide range of subjects in the area of fatigue.

## Conflict of interest

The authors have no conflict of interest whatsoever.

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