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Relationship between natural muscle oscillation frequency and lower limb muscle performance during instrumented sit-to-stand and stand-to-sit movements on a novel device in sedentary subjects

Maximiliano Torres-Banduc [a,b], Daniel Jerez-Mayorga [a,c,*,1], Luis Chirosa-Ríos [a], Paula Plaza [c], Ignacio Chirosa-Ríos [a]

[a] Department of Physical Education and Sports. Faculty of Sports Sciences, University of Granada, Granada, Spain
[b] Escuela de Kinesiología, Facultad de Ciencias de la Salud, Universidad de Las Américas, Viña Del Mar, Chile
[c] Exercise and Rehabilitation Sciences Institute, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile

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ABSTRACT

Background: Despite the significance of muscle oscillation frequency, previous research has not established a correlation with muscle performance due to the challenges of applying resistance without altering natural motion during functional tests.
Research question: What is the correlation between muscle oscillation frequency and lower limb muscle strength, power, and work during an instrumented sit-to-stand and stand-to- sit (iSTS-TS) task among sedentary subjects?
Methods: In a cross-sectional study, the oscillation frequency of the gastrocnemius medialis (GM), biceps femoralis (BF), and vastus medialis (VM) muscles in both the dominant (D) and non-dominant (ND) legs was assessed with a handheld myotonometer in 34 sedentary individuals before performing the iSTS-TS task.
Results: In the isokinetic mode, no significant correlations were found. In the isotonic mode, the BF muscle oscillation frequency in the D and ND legs exhibited significant positive correlations with peak force, peak power, and work during sitting down, as well as peak power and work during standing up. Positive correlations were observed in both legs between the GM oscillation frequency and sitting down peak force and work. Additionally, significant positive correlation was found with standing up work in the D leg. Muscle oscillation frequency of the VM exhibited a positive correlation with sitting down peak force in the ND leg.
Significance: Due to a greater number of correlations found, it is advisable to use the isotonic mode when assessing muscle oscillation frequency in relation to muscle performance during functional iSTS-TS tasks in sedentary subjects.

1. Introduction

In the lower extremities, sedentary lifestyle has been associated with a reduction in muscle mass [1], resulting in alterations in muscular performance, specifically in strength and power. However, a recent review highlighted that many of the mechanisms underlying the detrimental effects of a sedentary lifestyle on the musculoskeletal system and others remain unidentified [2]. Considering that the natural muscle oscillation frequency, as demonstrated by Viir, Laiho, Kramarenko and Mikkelsson [3], serves as a distinctive marker of innate tension within biological soft tissues, it assumes a significant role as a parameter in comprehending these effects. The significance of natural muscle oscillation frequency in understanding muscle behavior is underpinned by its correlation with the key elements of muscle function. For instance, it offers valuable insights into muscle tone [4], thereby shedding light on the muscle preparedness to contract and respond to stimuli. Elevated values of natural muscle oscillation frequency are indicative of heightened muscle tone [4] and have recently been used to predict thigh muscle strength [5].

In summary, the natural muscle oscillation frequency is relevant to muscle behavior because it provides valuable information about muscle tone, which, in turn, impacts various aspects of movement and muscle

* Corresponding author at: Cam. de Alfacar, 21, Granada 18071, Spain.
E-mail address: djerezmayorga@ugr.es (D. Jerez-Mayorga).
1 ORCID ID: 0000–0002-6878–8004.

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performance. Indeed, a recent study [6] attempted to establish a relationship between oscillation frequency and muscle function using a battery of functional tests (including sit-to-stand 5 and 60, timed up and go, short physical performance battery, gait speed, incremental shuttle walk, and postural sway). However, no significant association was found. Nevertheless, a recent review by Shukla, Bassement, Vijay, Yadav and Hewson [7] proposed that power and velocity parameters acquired from an instrumented sit-to-stand (iSTS) task may have the potential to enhance the detection of strength-related conditions, such as physical frailty, when compared with the standard sit-to-stand assessment. This observation might help explain the lack of correlation between the test values of Wilkinson et al. [6] and the muscle oscillation frequency.

However, it is important to note that few studies have addressed these issues, primarily due to the technical challenges associated with maintaining natural movement during single-joint isokinetic assessments [8]. Therefore, the use of a device, such as a functional electromechanical dynamometer, not only has the potential to enhance the applicability of the results [9] but may also allow for the determination of more precise values regarding muscle function by identifying the kinetic behavior of human movement during a functional and similar iSTS task, such as the instrumented Sit-to-Stand and Stand-to-Sit (iSTS-TS) task. It is important to consider that muscles may respond differently to isokinetic and isotonic modes of evaluation because of the nature of resistance. Isokinetic tests maintain a constant speed, whereas isotonic tests allow muscles to contract at varying speeds, mimicking real-world movements. This variability can reveal subtle differences in muscle behavior that might remain unnoticed when using a single testing modality.

Consequently, this study aimed to explore the relationship between muscle oscillation frequency and lower-limb muscle strength, power, and work during an iSTS-TS task in both isokinetic and isotonic modes in sedentary subjects. Given the relevance of natural muscle oscillation frequency to muscle function and the more natural approach of isotonic resistance, significant positive correlations between muscle oscillation frequency and lower-limb muscle strength, power, and work are expected in both testing modalities, with potentially stronger correlations observed in the isotonic mode.

2. Methods

2.1. Experimental design

In a cross-sectional study, muscle tone, peak strength, peak power, and work levels of the lower limbs were assessed in sedentary individuals during an iSTS-TS task. Following anthropometric evaluation, the participants were evaluated using a functional electromechanical dynamometer in both isokinetic (15 cm/s) [10] and isotonic (60 % of body weight) modes.

To increase testing reliability, one week before the start of the study, two 30-min familiarization sessions were held. The iSTS-TS test was explained and a practice trial for each modality (i.e., isokinetic and isotonic) was performed. The participants' dominant leg was determined using a two-step method. Initially, they were asked to self-report their dominant leg. This information was then confirmed by observing the consistent use of the reported dominant leg during a ball-kicking task. The subjects were instructed to avoid physical training 24 h before the testing session. The same research assistant conducted familiarization and testing sessions in the same laboratory.

2.2. Participants

Statistical software (G*Power, v3.1.9.7, Heinrich-Heine-Universität, Germany) was used to calculate the sample size. Considering a large effect size [11], desired power (1-ß error) = 0.90, and alpha error < 0.05, the total sample size was 25 participants. Considering potential attrition, the minimum initial sample size was set at 30 participants. The following eligibility criteria were applied: (i) absence of musculoskeletal injuries for the past two months prior to the start of the study, (ii) inability to undergo lower-extremity surgery in the previous year, (iii) sedentary status, as determined by the International Physical Activity Questionnaire [12] (must include low physical activity and equal to or more than 6 h of sedentary behavior), and (iv) no musculoskeletal issues that would limit their ability to perform at maximum effort during the testing procedures. A total of 33 sedentary individuals (41 % female; age:24.7 ± 5.6 years; body mass:76.52 ± 15.5 kg; height:1.69 ± 0.1 m; and body mass index:26.6 ± 4.4 kg/m2) (Table 1) participated in the study. All experimental methods were conducted in accordance with the recommendations of the latest version of the Declaration of Helsinki. Informed consent was obtained from all participants before participation, and the study design was approved by the ethics board of the Universidad de Granada, nº:2294/CEIH/2021.

2.3. Data recordings

2.3.1. Anthropometric evaluation

Body mass was measured using a calibrated mechanical scale (SECA model 711, Hamburg, Germany) with a precision of 0.1 kg. The standing height was measured using a telescopic scale (SECA, model 220, Hamburg, Germany), with an accuracy of 0.1 cm. The subjects were tested using light clothing (with the footwear removed).

2.3.2. iSTS-TS evaluation

Lower limb strength, power and work during the iSTS-TS task were evaluated with a functional electromechanical dynamometer (FEMD) (DynaSystem, Model Research, Spain) with a precision of 3 mm for displacement, 100 g for detected loads, a sampling frequency of 1000 Hz, and a speed range between 0.05 m/s and 2.80 m/s [10]. During the assessment, the participants maintained a seated position with their hip and knee joints flexed at approximately 90 °. The iSTS-TS protocol was systematically assessed using an isokinetic mode at a velocity of 15 cm/s in conjunction with an isotonic mode calibrated to 60 % of the subject's body weight. This approach was chosen because both modalities have demonstrated high reliability [9] and because muscles may respond differently to isokinetic and isotonic modes because of the nature of the resistance. The isokinetic resistance is constant, whereas the isotonic resistance varies with movement. This variability can reveal subtle differences in muscle behavior that might not be evident when using a single testing modality.

During the task, the participants marked a comfortable foot distance on the platform to maintain consistency in the repetitions. The subjects were equipped with a vest that featured secure anchorage at the xiphoid process to which the dynamometer was attached. Three attempts were made for each task within the iSTS-TS. They were instructed to keep their hands crossed against their chest and to stand up quickly without lifting their feet off the platform [9] (Fig. 1). This specific phase was labeled the 'standing up' task [13]. Subsequently, the participants returned to the sitting position, designated as the "sitting down" task [13]. Throughout the procedure, participants were encouraged to exert maximum effort, adhere to standardized verbal guidelines, and refrain from lifting their feet off the platform. Hence, the primary metrics used to assess lower limb performance were peak force (kg), peak power (W), and work (J)

Table 1
Basic descriptive characteristics of the sample.

	Sample (n=33)
Gender	41 % females; 59 % males
Age (years)	24.7 ± 5.6
Body mass (kg)	76.52 (±15.5)
Height (cm)	1.69 (±0.1)
Body mass index (kg/m^2)	26.6 (±4.4)

Fig. 1. Measurement of force, power, and sEMG during dynamometric evaluation of the iSTS in a representative female participant.

2.3.3. Muscle tone

Considering their relevance for knee and ankle movement during sit-to-stand [14], the tones of the BF, GM, and VM were assessed using a handheld myotonometer (MyotonPRO, Estonia), the reliability of which has been previously reported [3,15]. The device measures the oscillation frequency (Hz) in a relaxed muscle state, which serves as an indicator of muscle tone. To ensure precision, the sensing probe of the myotonometer was placed on each muscle according to the manufacturer's recommendations (https://www.myoton.com/applications/). Once the proper location was determined, constant, moderate pressure was applied to the muscle in a relaxed state for 3–5 s (Fig. 2). The mean muscle tone was calculated based on the results of three trials. If the coefficient of variation between the trials exceeded 10 %, the evaluation was repeated until the criteria were satisfied.

Fig. 2. Measurement of muscle oscillation frequency of the gastrocnemius medialis using a myotonometer in a representative male participant.

2.4. Statistical analyses

The normality of the data was confirmed using the Shapiro-Wilk test ($p > 0.05$), and the equality of variances was assessed using Levene's test ($p > 0.05$). Descriptive data are presented as the mean ± SD. Pearson's product-moment correlation coefficient (Pearson's r) was used to quantify the correlation between outcomes. The magnitude of the correlation was interpreted as null (0.00–0.09), small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–0.89), nearly perfect (0.90–0.99), or perfect (1.00). Due to the consideration of multiple comparisons, the adjustment of P values was carried out utilizing the Benjamini–Hochberg method to control the false discovery rate at the 0.05 significance level [16]. Statistical analyses were performed using GraphPad Prism 8 (version 8.0.1).

3. Results

The correlations between muscle tone in the dominant (D) and non-dominant (ND) legs and the peak force, peak power, and work during the two phases of the iSTS-TS task (i.e., standing up and sitting down) in both isokinetic and isotonic modes are displayed in Table 2.

The results of the iSTS-TS task performed in isokinetic mode revealed no significant correlations. On the other hand, In the isotonic mode, we found significant positive correlations between muscle oscillation frequency and various measures of muscle performance in both the D and ND legs. Specifically, the GM muscle oscillation frequency in leg D showed significantly moderate to large positive correlations with sitting down peak force ($r = 0.573$, $p = 0.009$), work ($r = 0.497$, $p = 0.021$) (Table 2), and with standing up work ($r = 0.501$, $p = 0.026$).

Additionally, in the ND leg, the GM muscle oscillation frequency showed significantly moderate to large positive correlation with sitting down peak force ($r = 0.528$, $p = 0.016$) (Table 2).

Furthermore, the muscle oscillation frequency of the BF also exhibited significantly moderate to large positive correlations with specific measures in the D leg. The BF muscle oscillation frequency was significantly positively correlated with sitting down peak force ($r = 0.600$, $p = 0.009$), and work ($r = 0.584$, $p = 0.009$). The same was observed for the standing up work ($r = 0.554$, $p = 0.009$) (Table 2).

Moreover, in the ND leg, the BF muscle oscillation frequency showed significant moderate to large positive correlations with sitting down peak force ($r = 0.615$, $p = 0.009$), peak power ($r = 0.465$, $p = 0.038$), and work (r = 0.569, p = 0.009). The same was observed for the standing up peak power ($r = 0.557$, $p = 0.009$), and work ($r = 0.542$, $p = 0.009$) (Table 2). Additionally, the VM also exhibited moderate positive correlations with sitting down peak force ($r = 0.473$, $p = 0.036$).

4. Discussion

This study aimed to explore the relationship between muscle oscillation frequency and lower-limb muscle strength, power, and work during an iSTS-TS task in both isokinetic and isotonic modes in sedentary subjects. Moderate to large positive correlations were observed between the muscle oscillation frequency of all the tested muscles and muscle performance measures for both legs in isotonic mode, whereas in isokinetic mode, no significant correlations were found. In summary, the findings of this study suggest that there is a positive relationship between muscle oscillation frequency and lower-limb muscle strength, power, and work, particularly in isotonic mode. These results provide insights into the relationship between muscle oscillation and performance in different modes of the iSTS-TS task, potentially contributing to a better understanding of muscle function in sedentary individuals.

Table 2
Relationship between the muscle oscillation frequency of dominant, non-dominant leg, and standing up and sitting down peak force, peak power and work during the iSTS at 15 cm/s and 60 % body weight.

iSTS-TS at 15 cm/s		Muscle oscillation frequency (Hz)											
		BF				VM				GM			
		D		ND		D		ND		D		ND	
		r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Peak force	standing up	0.232	0.288	0.353	0.128	-0.008	0.965	0.237	0.288	0.299	0.170	0.409	0.080
	sitting down	0.072	0.767	0.230	0.288	-0.055	0.807	0.200	0.347	0.212	0.316	0.309	0.169
Peak power	standing up	0.184	0.379	0.230	0.170	-0.046	0.833	0.193	0.358	0.280	0.196	0.427	0.072
	sitting down	0.057	0.807	0.223	0.297	-0.068	0.774	0.197	0.351	0.213	0.316	0.310	0.169
Work	standing up	0.121	0.579	0.232	0.288	-0.081	0.740	0.158	0.464	0.306	0.169	0.349	0.128
	sitting down	0.145	0.504	0.314	0.169	-0.013	0.965	0.303	0.169	0.224	0.297	0.340	0.139
iSTS-TS at 60 % body weight		Muscle oscillation frequency (Hz)											
		BF				VM				GM			
		D		ND		D		ND		D		ND	
		r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Peak force	standing up	0.232	0.288	0.306	0.169	0.008	0.965	0.135	0.535	0.377	0.103	0.290	0.181
	sitting down	0.600*	**0.009**	0.615*	**0.009**	0.404	0.083	0.473*	**0.036**	0.573*	**0.009**	0.528*	**0.016**
Peak power	standing up	0.408	0.080	0.557*	**0.009**	0.338	0.139	0.398	0.086	0.261	0.238	0.367	0.113
	sitting down	0.430	0.072	0.465*	**0.038**	0.283	0.195	0.388	0.091	0.365	0.115	0.320	0.166
Work	standing up	0.554*	**0.009**	0.542*	**0.009**	0.251	0.258	0.304	0.169	0.501*	**0.021**	0.390	0.091
	sitting down	0.584*	**0.009**	0.569*	**0.009**	0.322	0.166	0.361	0.115	0.497*	**0.026**	0.410	0.080

BF= biceps femoral; VM= vastus medialis; GM= gastrocnemius medialis; D= dominant; ND=non-dominant *= significant positive correlation; p= Benjamini-Hochberg adjusted P values (false discovery rate) in bold indicate statistical significance ($p < 0.05$). r = Pearson's product-moment correlation coefficient.

This study demonstrated that muscle oscillation frequency correlates with muscle peak force, peak power, and work during functional movement, regardless of leg dominance. Notably, our findings indicate that in cases where the iSTS-TS is velocity-dependent (isokinetic mode), there were no correlations observed between the oscillation frequency of the tested muscles and muscle performance. However, in force-dependent situations (isotonic mode), the BF, VM, and GM exhibit moderate to large correlations. These results underscore the significant role played by the oscillation frequency of these muscles in both legs in iSTS-TS performance. Particularly, the relevance of the GM found in the present study is in line with a previous study [17], where a higher Achilles tendon oscillation frequency was correlated with increased countermovement jump height. This suggests that the GM muscle-tendon mechanical properties play a significant role in lower limb performance, especially in movements that involve a stretch-shortening cycle. However, future research is needed to determine whether training can influence the oscillation frequency of the muscle and tendon and subsequently enhance lower limb performance during functional tasks in sedentary subjects. Conversely, Wilkinson, Gore, Baker and Smith [6] found no consistent or substantial correlation between the muscle oscillation frequency and physical performance in functional tests. The variance in the results between their study and the present study may be attributed to two factors. First, they exclusively assessed the rectus femoris, overlooking other muscles crucial for tasks, such as sit-to-stand. Previous research indicates that the tibialis anterior and vastus medialis exhibit the highest percentage contribution to this activity [18]. Second, they did not use instrumented equipment to assess subjects' performance during sit-to-stand, despite a recent review by Shukla, Bassement, Vijay, Yadav and Hewson [7] that established that power and velocity parameters acquired from an iSTS task may have the potential to enhance the detection of strength-related conditions compared to the standard sit-to-stand assessment. This implies that considering multiple lower limb muscles, especially in velocity-dependent functional tasks, and utilizing instrumented equipment for assessment, can offer a more comprehensive understanding of the relationship between muscle oscillation frequency and lower limb muscle performance. Such insights can serve as valuable information for designing tailored interventions for strength-related conditions.

The scarcity of significant relationships between vastus medialis (VM) oscillation frequency and sit-to-stand performance found in the present study raises an intriguing point, considering the pivotal role of the quadriceps in generating the necessary force and power for this task [18]. While intuitively, one might expect a strong correlation between VM oscillation frequency and sit-to-stand performance, the present findings suggest a more complex relationship. Several factors could contribute to this discrepancy, including the involvement of other synergistic or compensatory muscles, individual biomechanical variations, and potentially the specific conditions of the task execution.

Indeed, at least three types of synergies have been reported in young adults during the sit-to-stand task in a recent scoping review [19], with almost all of these synergies considering vastus lateralis and not vastus medialis. The aforementioned could explain the lack of correlations of this muscle and iSTS-TS task performance. Regarding biomechanical variations, pelvic tilt affects the level of activation of vastus medialis in the sit-to-stand procedure, with a neutral pelvic tilt versus an anterior pelvic position increasing activation of the vastus medialis oblique and vastus lateralis [20], In this sense, an anterior pelvic tilt during the iSTS-TS task could account for explaining the lack of correlations. However, since this was not measured, future studies should control for this issue.

Another crucial consideration was the choice of modality for assessing the iSTS-TS task. In the current study, the BF, VM and GM demonstrated moderate to large positive correlations, but only in isotonic mode. This could be explained by several factors.

First, the testing modality, whether isokinetic or isotonic, significantly affected muscle activation patterns during the task. Isokinetic testing involves a constant speed of movement, which may not replicate the natural muscle activation patterns observed during functional tasks, such as standing up or sitting down. In contrast, isotonic testing permits a more natural range of motion and muscle activation, potentially leading to different correlations with the task performance. This aligns with findings from previous studies [9], which recommend a force-dependent modality (isotonic) owing to its ecological approach. In short, the aforementioned could explain the moderate-to-large correlation found between muscle oscillation frequency and muscle performance in the isotonic modality.

Additionally, variations in the correlations can be attributed to the inherent kinematic specificity of the task [21]. The act of standing up and sitting down involves intricate movements that engage various muscle groups, each contributing differently to a task [18,22]. Isotonic testing may better capture the nuanced interactions between these muscles, resulting in stronger correlations between the measured muscles and task performance.

Furthermore, the biomechanical demands of the iSTS-TS task may favor certain muscle groups in one testing modality over others. Indeed, a recent study established that performing sit-to-stand-to-sit at a fast speed could be more challenging for participants than doing so at their preferred speed [23]. For instance, the emphasis on concentric and eccentric muscle actions during isotonic testing aligns more closely with the requirements for standing up and sitting down.

Above all, the choice of testing modality is a critical factor when evaluating the relationship between the oscillation frequency of specific muscles and their influence on the execution of the iSTS-TS task. Understanding the differences between isokinetic and isotonic testing is essential for the accurate assessment and interpretation of these relationships, which can have implications for exercise prescription, rehabilitation, and other applications related to lower limb muscle function and performance.

From a practical perspective, while oscillation frequency may serve as a marker for muscle tone, it is not solely indicative of muscle strength or weakness. Research suggests that resting muscle tone can be influenced by various factors, including neural input, muscle activity, and mechanical factors [24]. Thus, different types of training (i.e. plyometric) targeting these factors are expected to improve muscle tone, and muscle oscillation frequency.

Resistance training and practicing functional movements, like sit-to-stand exercises, enhance lower limb power and muscle quality [25], potentially improving resting muscle tone. In this regard, the necessity of measuring oscillation frequency in clinical decision-making regarding exercise training shows promise. Indeed, it may offer supplementary insights into muscle function, and its potential role in guiding exercise interventions beyond conventional measures like strength and power is encouraging. This notion is supported by recent research indicating that muscle oscillation frequency can predict thigh muscle strength in the athletic population [5]. However, whether this can be accounted for in other special populations warrants further investigation.

Of note, the applicability of these results to patients with tone-related pathologies requires careful consideration. While the mechanisms underlying muscle tone and oscillation frequency may differ in these populations due to the specific nature of their conditions, interventions aimed at improving muscle strength and function through resistance training and functional exercises may still be beneficial. However, individualized approaches accounting for the unique characteristics of each pathology are essential. Further research is needed to determine the effectiveness of specific interventions targeting oscillation frequency and its relevance in clinical management across different tone-related pathologies.

4.1. Limitations

The evaluation of force, power and work was bilateral, hindering the comparative analysis between limbs, to address this limitation, future research could consider including measures that differentiate between unilateral and bilateral force power and work. The cross-sectional design employed in this study presents limitations in establishing causal relationships. Future longitudinal studies hold the potential to delve deeper into the temporal dynamics of muscle oscillation frequency and performance changes. Moreover, incorporating electromyography and broadening the scope of muscles assessed in the iSTS-TS task could yield a more comprehensive understanding of muscle function. Furthermore, given that muscle tone is influenced by various factors such as neurological and temperature, the integration of additional measures could enhance the accuracy and applicability of the results. This approach would ultimately lead to a more thorough understanding of the impact of these variables on iSTS-TS task performance.

5. Conclusions

This investigation revealed that sedentary individuals display positive correlations between muscle oscillation frequency and muscle performance variables, with stronger and exclusive associations observed in isotonic mode. From a practical standpoint, it is advisable to use the isotonic mode when assessing muscle oscillation frequency in relation to muscle performance during functional Sit-to-Stand and Stand-to-Sit tasks in sedentary subjects. Future research should provide information on causation between the variables reported in this study.

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CRediT authorship contribution statement

Daniel Jerez-Mayorga: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Investigation, Formal analysis, Conceptualization. **Paula Plaza:** Writing – review & editing, Visualization, Formal analysis. **Luis Chirosa-Ríos:** Writing – review & editing, Visualization, Supervision, Project administration, Conceptualization. **Ignacio Chirosa-Ríos:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Formal analysis, Conceptualization. **Maximiliano Torres-Banduc:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

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