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Exploring temporal congruence in motor imagery and movement execution in non-specific chronic low back pain

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A R T I C L E I N F O

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A B S T R A C T

Chronic non-specific low back pain (NSCLBP) is linked to sensorimotor dysfunctions and altered motor planning, likely due to neuroplastic changes. Motor imagery (MI) and movement execution share neural pathways, but the relationship between imagined and executed movements in NSCLBP patients remains underexplored. This study aimed to assess the temporal congruence between imagined and executed movements in NSCLBP sufferers, with secondary goals of investigating group differences in movement chronometry, psychological well-being, and disability, as well as possible correlations among these factors. Fifty-six participants, including 28 NSCLBP patients and 28 asymptomatic subjects (AS), performed lumbar flexion and Timed Up and Go (TUG) tasks. NSCLBP patients showed significant temporal incongruence in both tasks, executing movements more slowly than imagined, whereas AS displayed incongruence only in the TUG task. NSCLBP patients also took longer to imagine and execute lumbar flexion movements compared to AS, with correlations observed between execution delays, higher disability, and greater fear of movement. The findings highlight a lack of temporal congruence in NSCLBP patients, especially in lumbar flexion, emphasizing the complex relationship between chronic pain, motor ability, and psychological factors. These results suggest that integrated treatment approaches addressing cognitive and emotional aspects are crucial for managing NSCLBP.

1. Introduction

Low back pain (LBP) is a prominent musculoskeletal problem with significant socioeconomic impact (Hoy et al., 2012). It is a leading cause of work absence and is the third most disabling disease after ischemic heart disease and chronic obstructive pulmonary disease (Murray et al., 2015). Most cases of LBP correspond to nonspecific chronic low back pain (NSCLBP), described as discomfort in the lumbar region, persisting for more than 3 months, without an identifiable cause (Hartvigsen et al., 2018).

It is essential to consider LBP as a multidimensional experience influenced by physical, cognitive, neurophysiological, psychological, and social factors (Buruck et al., 2019; Yang et al. 2023). These factors can promote the persistence of symptoms and potentially induce maladaptive neuroplastic changes at the spinal and supraspinal levels (Hashmi et al., 2013; Subramanian & Venkatesan, 2022). Likewise, in chronic neck pain, maladaptive pain behavior and a pain memory that could be modulated by contextual factors have been observed (Beinert, 2017).

Chronic low back pain (CLBP) is not only associated with sensorimotor deficits such as reduced lumbosacral tactile and proprioceptive acuity and postural control deficits but also with changes in brain activation. Goossens et al. (2018) reviewed functional magnetic resonance imaging (fMRI) studies suggesting a reorganization of lumbar spine representation in multisensory and motor processing brain areas in patients with CLBP. These changes include reduced activations in the

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primary and secondary somatosensory cortices, the supplementary motor area, and the superior temporal gyrus, as well as increased activation in regions associated with abnormal pain processing (Goossens et al., 2018).

Motor imagery (MI) has been used for many years as a manner of mental rehearse or practice the movements in many sports and dance, but is has been also explored the implementation of motor imagery for rehabilitation and motor training (MacIntyre et al., 2018). It is based on a mental reproduction of the movement which leads to a movement representation at the cortical areas with no actual movement happening (Jeannerod & Frak, 1999), in other words, MI refers to a dynamic cognitive process that allows the internal representation of motor actions without their actual execution (Decety, 1996b).

Zhang et al. (2012) reviewed the neural basis of MI and its impact on motor learning and performance. Using neuroimaging techniques like fMRI and transcranial magnetic stimulation (TMS), they demonstrated that MI involves many of the same brain areas as actual motor execution. MI can improve motor performance and accelerate the learning of motor skills, possibly due to the activation and strengthening of neural connections involved in motor execution (Zhang et al., 2012).

The MI activates brain regions involved in the process of planning and managing movement, in a manner analogous to when the movement is actually carried out (Decety, 1996b, 1996a). Similar neural networks are activated in MI compared to the real movement, which include premotor cortex, supplementary motor area (SMA), inferior, posterior and superior parietal lobe, thalamus (ventral caudal and ventral intermediate) basal ganglia, cingulate cortices and cerebellum, areas related to motor planning, preparation and execution (Anderson et al., 2011; Ehrsson et al., 2003; Gerardin, 2000; Hanakawa et al., 2003; Hanakawa et al., 2005; Iseki et al., 2008; Wriessnegger et al., 2017). Corticospinal excitability has been found to increase during MI similar to motor performance, however a lack of motor output has been identified, so peripheric inhibition of the execution of movement must be happening at some point (Chong & Stinear, 2017). Yang et al. (2023), through fMRI and multi voxel pattern analysis (MVPA), showed that MI and motor execution activate similar brain regions however using different neural codes (Yang et al., 2023a,b).

The activation of these areas has been found to be stronger for complex sequential movements compared to simple repetitive ones, obtaining greater left-hemispherical activity for the simple task and bilateral hemispherical activity for the motor imagery complex task (Kuhtz-Buschbeck et al., 2003). Also, a better imagery ability lead to a greater activation of motor areas and prefrontal executive area during motor imagery (van der Meulen et al., 2014). Furthermore, Rodriguez et al. (2008) argue that the ability of MI to produce "realistic" simulations of movement varies depending on the motor task (Rodriguez et al., 2008).

A relevant aspect of MI is temporal congruence, that is, the relationship between the execution times of imagined and performed movements (Kemlin et al., 2016). Some of the characteristics identified to influence temporal congruency are the type of task, the level of movement automatization, complexity, and the context in which the movement is performed (Paris-Alemany et al., 2019; Rodriguez et al., 2008).

An appropriate temporal congruence seems to indicate that there is an accurate representation of the movement (Greiner et al., 2014), supported by studies showing similarity or synchrony between the execution and imagination times of movements (Decety & Michel, 1989; Greiner et al., 2014). Temporal congruence also supports the idea that the brain processes both real and imagined movement in a similar manner (Jeannerod, 2001). This phenomenon has been studied in healthy populations and in certain pathological conditions, specifically, we have evidence in stroke, showing significant variations in temporal congruence (Kemlin et al., 2016; Rodriguez et al., 2008). After a stroke, bilateral slowing of mentally simulated actions was observed for both limbs (both hemispheres), affected and non-affected. The real movement was faster in the unaffected limb, causing temporal incongruence between motor imagery and movement execution due to the timing difference (Malouin et al., 2004). Therefore, the lack of temporal congruence can be relevant for identifying alterations in the central nervous system, as has been identified in patients with neurodegenerative diseases or motor disorders (Sirigu et al., 1996).

Regarding chronic pain, a cortical over-activity was found in central chronic pain patients during motor imagery, which can be normalized by rehabilitation strategies (Hasan et al., 2016). Beinert (2017) investigated the neural correlates of maladaptive pain behavior in chronic neck pain using fMRI. The study found that imagined head rotation in a non-distracted context and toward the painful side caused greater activation in pain-processing areas, such as the primary somatosensory cortex, thalamus, insula, anterior cingulate cortex, and prefrontal cortex, compared to a distracted context or movement to the non-painful side (Beinert, 2017).

In the context of NSCLBP, MI has been insufficiently investigated, although some findings have emerged. Previous studies have demonstrated that patients with NSCLBP experience difficulties in generating motor images (La Touche et al., 2019; Ozlem & Karaali, 2022). Specifically, it has been observed that these patients exhibit reduced brain activity in regions associated with MI, left supplementary motor area and right superior temporal sulcus (Vrana et al., 2015). Also enhanced functional connectivity indicating diffuse and non-specific changes in NSLBP patients' cortical processing (Vrana et al., 2015).

The relationship between temporal congruence and neurophysiological changes in NSCLBP remains underexplored. Given the existing evidence and limitations in the previous literature, our hypothesis was that patients with NSCLBP will experience interference in their brain activity when performing MI, potentially resulting in altered temporal congruence between MI and actual movement execution. Therefore, the primary objective of this study was to evaluate the temporal congruence between imagined and executed movements in patients with NSCLB. The secondary objective was to analyze potential differences between groups in chronometry, psychological and disability variables, and to identify any associations between these variables.

2. Methods

2.1. Study design

A cross-sectional observational study was conducted in patients with NSCLBP. The study protocol follows the Standards for the Reporting of Observational Studies (STROBE) statement **(Annex 1)**. The procedure of this study has been approved by the ethics committee of the X (Blinded X/X) and in accordance with the Declaration of Helsinki **(Annex 2)**. Participants were recruited from December 2021 to July 2022. Patients with NSCLBP came from various private physiotherapy clinics in Madrid, and asymptomatic subjects (AS) were recruited by telephone or verbal communication in the Madrid community.

The inclusion criteria for the symptomatic group were a) Subjects with NSCLBP of at least 3 months duration; b) Men and women aged between 18 and 65 years; c) NSCLBP with a frequency of at least 10 days per month, and d) Presenting with a pain intensity of at least 3/10 on the Numeric Rating Scale (NRS). As for the inclusion criteria for the AS group, they were a) Subjects who do not suffer from acute or CLBP; b) Men and women aged between 18 and 65 years; c) Participants without the presence of systemic, neurological diseases, or cognitive or psychological disorders. The exclusion criteria were a) Comorbidities such as neurological signs (weakness in lower limbs), systemic rheumatic diseases (including fibromyalgia), or central nervous system diseases; b) Presence of diagnosed psychiatric illness or severe cognitive impairment; c) Illiteracy; d) Difficulties in understanding and communication; e) Insufficient knowledge of Spanish, and f) Participants who were studying for a degree in Physiotherapy or Occupational Therapy.

For the final experimental study, a total of 28 participants were included in each group (NSCLBP and AS), in line with the sample size estimation derived from the pilot study.

2.2. Procedure

After confirming compliance with the inclusion and exclusion criteria and providing a verbal explanation and information sheet about the study protocol, participants were asked to sign an informed consent form. Demographic data were collected from each participant, and they completed a series of questionnaires on fear of movement, level of physical activity, self-efficacy regarding chronic pain, lumbar disability, and the ability to generate kinesthetic and visual motor images.

The assessment continued by offering participants the observation of a video with the movements on which the evaluation was based: lumbar flexion and the Timed Up and Go (TUG) test. Subsequently, participants were asked to imagine the lumbar flexion gesture they had previously visualized, and the time taken to imagine was timed, followed by the same process with the TUG. Finally, participants were asked to perform each of the movements while the time taken to complete them was timed.

2.3. Main Outcome measure

2.3.1. Temporal congruence

To assess temporal congruence, the MI chronometry and the execution chronometry were used (Williams et al., 2015). This involved quantifying the time taken by the subject in the process of imagining the gesture of lumbar flexion and, on the other hand, the sequence of movements of the TUG test. The recorded time corresponded to the interval between the start command of the task and the verbal response from the participant for the mental task, or until the completion of the executed motor gesture was observed.

The tasks chosen for this study were a movement and a sequence of movements. Lumbar flexion is a test commonly performed on patients with NSCLBP (Laird et al., 2019). It was conducted as follows: from a standing position, the patient was asked to bend their body forward as much as possible, bringing their hands towards the ground, and once reaching the maximum flexion position, to return to the initial position. On the other hand, a sequence of movements based on the TUG was used. This test involves the participant getting up from a standard chair, walking 3 m to a mark on the floor, circling it, returning to the chair, and sitting down again. The time required to complete this task is measured with a stopwatch. This test has good test–retest reliability with an intraclass correlation coefficient (ICC) greater than 0.98, (Simmonds et al., 1998). The imagined TUG has been used in other populations such as older adults and multiple sclerosis (Allali et al., 2012; Beauchet et al., 2010).

2.4. Secondary variables

2.4.1. Pain intensity

Pain intensity was quantified using the NRS, a tool consisting of a numeric line from 0 to 10, where 0 represents “no pain” and 10 indicates “maximum tolerable pain.” The NRS has been extensively validated as a reliable and precise instrument for pain quantification, showing excellent test–retest reliability (ICC = 0.94) (Ferraz et al., 1990).

2.4.2. Physical activity level

The level of physical activity was assessed using the short version of the International Physical Activity Questionnaire (IPAQ-S) in its short form, translated into Spanish. It classifies adult populations based on their levels of physical activity into three types: vigorous, moderate, and walking. This questionnaire has shown to have a reliability of 0.65 (r = 0.76; 95 % CI: 0.73–0.77) and adequate validity (r = 0.67; 95 % CI: 0.64–0.70) (Toloza et al., 2007).

2.4.3. Pain-Related fear

The assessment of kinesiophobia, or fear of movement related to pain, was conducted using the 11-item Spanish version of the Tampa Scale for Kinesiophobia (TSK-11). This instrument has demonstrated robust reliability and validity metrics (Cronbach’s alpha: 0.7–0.9), ensuring its efficacy in measuring the construct of interest. The TSK-11 is structured into two subscales that distinctly measure fear of engaging in physical activity and fear of incurring harm due to such activities. The scoring range of the TSK-11 spans from 11 to 44, with elevated scores indicative of a more pronounced perception of kinesiophobia. This bifurcated approach facilitates a nuanced understanding of the psychological barriers to physical activity presented by pain-related fear, delineating between general activity aversion and specific anxieties concerning physical harm (Gómez-Pérez et al., 2011).

2.4.4. Lumbar disability

Physical disability due to low back pain was assessed using the Spanish version of the Roland-Morris Disability Questionnaire (RMDQ), which has shown to have acceptable psychometric properties. The RMDQ is a self-administered questionnaire of 24 items, with a total score ranging from 0 to 24, where higher scores indicate higher levels of disability. The questionnaire has acceptable reliability (Cronbach α, 0.91) (Kovacs et al., 2002).

2.4.5. Self-Efficacy in chronic pain

Self-efficacy was assessed using the Spanish version of the Chronic Pain Self-Efficacy Scale (CPS-ES), which has shown to have acceptable psychometric properties. The scale was developed to measure perceived self-efficacy and the ability to cope with the consequences of pain in patients with chronic pain. This 19-item scale is a self-administered instrument with 3 domains that assess self-efficacy for pain management, physical functioning, and symptom coping, with higher scores indicating greater self-efficacy for pain management. The questionnaire shows excellent validity (Cronbach α, 0.91) (Martín-Aragón et al., 1999).

2.4.6. Ability to generate kinesthetic and visual motor images

The Movement Imagery Questionnaire Revised (MIQ-R) was used to assess subjects’ MI ability. The questionnaire has a total of 14 items divided into two subscales, one measures kinesthetic imagery (MIQ-R_K) and the other visual (MIQ-R_V). Subjects rate from 1 to 7 the difficulty of imagining the actions with 7 being “very easy to imagine” and 1 “very difficult to imagine” (Cantalejo-Fernández et al., 2021). The internal consistency of the MIQ-R has proven to be adequate, indicating a Cronbach’s alpha coefficient above 0.84 for the total inventory and 0.80 for the visual subscale and 0.84 for the kinesthetic subscale (Campos & González, 2010). Regarding the MIQ-R variable, we have calculated the average chronometry for the MIQ-R_K and MIQ-R_V tests.

2.5. Sample size

A pilot study determined the effect size between the NSCLBP group and the AS group using the variable of time spent imagining the lumbar flexion gesture. A pilot study determined the effect size between the NSCLBP group and the AS group using the variable of time spent imagining the lumbar flexion gesture. The pilot study included a total of 12 participants per group and obtained an effect size f of 0.496 for a partial eta squared ($\eta p2$) of 0.198. The sample size was calculated using the G*Power 3.1.7 for Windows program (G*Power© by the University of Dusseldorf, Germany). It was calculated using the repeated measures Analysis of Variance (ANOVA) between groups with an α error level of 0.05, a statistical power of 95 % (1-β error probability), and an effect size of 0.496. For the final experimental study, a total of 28 participants were included in each group (NSCLBP and AS), in line with the sample size estimation derived from the pilot study.

2.6. Statistical analysis

The statistical analysis was conducted using SPSS version 29.0 (SPSS, Inc, Chicago, IL), with a significance level set at $p < 0.05$. The normality of the distributions was assessed using the Shapiro-Wilk test, complemented by visual inspection of Q-Q and P-P plots for a more detailed evaluation. Homogeneity of variances was evaluated through plots of residuals versus fitted values, indicating random dispersion without patterns, which suggests homogeneity. The independence of observations was verified using the Durbin-Watson statistic, with values close to 2.0 indicating no evidence of autocorrelation. Additionally, linearity was confirmed by observing a linear relationship in scatter plots of observed versus predicted values and in normal P-P plots of standardized residuals.

Demographic data were analyzed with descriptive statistics and represented as mean ± standard deviation (SD). In addition, Pearson's Chi-squared test was used to analyze differences between groups in categorical variables such as sex or education level and were represented as a percentage (%). An independent samples T-test was used to evaluate intergroup differences with respect to sensorimotor and psychological variables.

A repeated measures ANOVA was employed to examine differences between and within groups for each task (i.e., lumbar flexion and TUG test) independently. Given the distinct nature of these tasks, the analysis was performed separately to capture task-specific interactions between groups (NSCLBP patients and AS) and within tasks (MI process and movement execution).

In addition to the primary analyses, we included all sensorimotor and psychological variables (kinesiophobia, chronic pain self-efficacy, physical activity, and motor imagery ability) as covariates in the repeated measures ANOVA models to assess their potential influence on the performance of lumbar flexion and the Timed Up and Go (TUG) test. These covariates were chosen based on their relevance to the study's primary outcomes.

The Bonferroni post-hoc test was applied to identify significant differences in pairwise comparisons.

The effect size of the ANOVA test was estimated with η_p^2, considering the range 0.01 – 0.059 as a small effect size, 0.06 – 0.139 as a medium effect size, and values above 0.14 as large effect sizes. On the other hand, Cohen's d was used as an estimator of effect size in post-hoc comparisons. According to the established values to interpret Cohen's d, effect sizes below 0.49 were considered small, effect sizes between 0.50 and 0.79 were considered medium, and effect sizes above 0.80 were considered large (Cohen, 1988).

The relationships between psychological variables, as well as physical variables, were examined using Pearson correlation coefficients. A Pearson correlation coefficient greater than 0.70 indicates a strong correlation, a coefficient between 0.40 and 0.69 indicates a moderate correlation, and a coefficient below 0.39 indicates a weak correlation (Schober et al., 2018).

Two multiple linear regression analyses were employed to estimate the strength of the association between the chronometry of lumbar flexion MI and execution (criterion variables) and the self-reported psychological, disability, and MI ability measures (predictive variables) that exhibited a moderate magnitude correlation (>.40) and were statistically significant. The Variance Inflation Factor (VIF) was calculated to determine if any of the models exhibited multicollinearity. A VIF value close to 1 indicates no multicollinearity (independent predictor variable), $1 < VIF < 5$ suggests moderate multicollinearity (predictor variables are moderately correlated with each other), and $VIF > 10$ indicates the presence of multicollinearity (predictor variables are dependent and highly associated with each other) (Belsley, 1991). The strength of the association was examined using regression coefficients (β), p-values, and adjusted R^2. We report the standardized β coefficients for each predictive variable included in the final models to allow direct comparison between predictive variables within the regression model and the criterion variable.

3. Results

3.1. Sociodemographic data

The sociodemographic variables are shown in Table 1. The outcomes of diagnostic analyses conducted to assess the validity of the two multiple linear regression models indicate that the models were acceptable. Homoscedasticity has been confirmed, as evidenced by the random scatter of residuals without any discernible pattern. The Durbin-Watson statistic yielded a value of 1.29 for the first model and 2.12 for the second model, suggesting an absence of autocorrelation within the models. Furthermore, the normal P-P plot of standardized residuals suggests a linear relationship. Regarding the evaluation of normality, the Shapiro-Wilk test and visual analysis through Q-Q plots revealed that four variables did not follow a normal distribution. Specifically, these were the results of the IPAQ, the chronometry measures from the MIQ-R, and the lumbar flexion MI chronometry for the AS group. For the NSCLBP patient group, the variables that did not exhibit normality were the chronometry measures from the MIQ-R.

Although four variables did not meet the normal distribution criteria according to the Shapiro-Wilk test and visual inspections, parametric statistical analyses were applied to all variables, as the majority followed a normal distribution, and parametric tests are robust in handling such data discrepancies.

3.2. Temporal congruence between imagined and actual movement.

The ANOVA showed significant changes in the task factor ($F = 5.83$; $p = 0.019$; $\eta_p^2 = 0.097$) but not in the task*group interaction ($F = 1.35$; $p = 0.29$; $\eta_p^2 = 0.024$) for the lumbar flexion gesture when comparing times obtained in imagery chronometry and execution chronometry.

The repeated measures ANOVA showed that the interaction between time and kinesiophobia was statistically significant for lumbar flexion ($F = 7.203$, $p = 0.010$, $\eta_p^2 = 0.120$), demonstrating that kinesiophobia had a significant impact on the timing differences between the imagined and actual movements.

When considering the subscales of the TSK-11 as covariates, significant interactions were found. The interaction between time and the avoidance subscale was significant ($F = 7.19$, $p = 0.010$, $\eta_p^2 = 0.12$),

Table 1
Descriptive statistics of demographic data.

Measures	NSCLBP_group (n = 28)	Asymptomatic_group (n = 28)	P −value (T-test or chi-square test)
Aged [a]	46.89 ± 10.92	43.71 ± 12.84	0.162
Gender[b]			0.418
Male	10 (35.7)	14 (50)	
Female	18 (64.3)	14 (59)	
Educational level[b]			0.206
Primary education	2 (7.1)	1 (3.6)	
Secondary education	9 (32.1)	4 (14.3)	
University education	17 (60.7)	23 (82.1)	
Pain intensity	4.83 ± 1.7	–	–
Chronicity (months)	49.7 ± 50.2	–	–
Pain frequency (days/month)	21.29 ± 9.84	–	–
Disability	6.46 ± 5.10	–	–
Medication			0<.001
Yes	21 (75.0)	6 (21.4)	
No	7 (25.0)	22 (78.6)	

Values are presented as mean ± standard deviation or number (%). a Independent T-test. b Chi-square test; NSCLBP: nonspecific chronic low back pain. Medications reported were nonsteroidal anti-inflammatory drugs (NSAIDs).

indicating that avoidance behaviors related to movement may be contributing to the temporal asynchrony observed in NSCLBP patients. Additionally, the harm subscale also demonstrated a significant interaction with time ($F = 4.78$, $p = 0.033$, $\eta_p^2 = 0.083$), suggesting that fear of harm plays a role, albeit to a lesser degree than avoidance.

Similarly, the ANOVA results indicated that disability was a significant covariate in the temporal congruence of lumbar flexion, with a significant time-disability interaction ($F = 8.597$, $p = 0.005$, $\eta_p^2 = 0.140$), suggesting that participants' perceived disability influenced the performance of lumbar flexion tasks.

The Bonferroni-adjusted *post-hoc* analysis revealed statistically significant intragroup differences between MI chronometry and actual movement chronometry only for the NSCLBP group ($p = 0.014$, $d = 0.38$), with longer times taken to execute than to imagine. On the other hand, statistically significant intergroup differences were also found in MI chronometry ($p = 0.008$; $d = 0.72$) and in movement chronometry ($p = 0.009$; $d = 0.72$), with the NSCLBP group taking longer to imagine and to execute the movement **(**Table 2**)**.

Regarding the TUG, the ANOVA showed significant changes in the task factor ($F = 313.1$; $p < 0.001$; $\eta_p^2 = 0.855$) but not in the task*group interaction ($F = 2.30$; $p = 0.135$; $\eta_p^2 = 0.042$). The Bonferroni-adjusted *post-hoc* analysis revealed statistically significant intragroup differences between MI chronometry and actual movement chronometry for the NSCLBP group ($p < 0.001$, $d = 2.14$) and also for the AS group ($p < 0.001$, $d = 2.26$), with longer times taken to execute the movement in both groups. On the other hand, no statistically significant intergroup differences were found in the time to imagine or the time to execute ($p > 0.05$) **(**Table 2**)**.

3.3. *Differences between groups for sensorimotor and psychological variables*

The Table 3 shows the comparisons made with the T-test, indicating statistically significant differences for all analyzed variables except for the kinesthetic chronometry of the MIQ-R.

3.4. *Correlation analysis*

Table 4 presents the results of the correlation analysis examining the bivariate relationships between MI chronometry and execution chronometry for movements and psychological variables. Below we mention the strongest correlations.

For the NSCLBP group, moderate positive correlations were found between disability and both MI chronometry ($r = 0.431$; $p = 0.022$) and execution chronometry of the lumbar flexion movement ($r = 0.585$; $p = 0.001$); and between kinesiophobia and execution chronometry of the lumbar flexion ($r = 0.576$; $p = 0.001$) was found. Additionally, moderate negative correlation was found between MI chronometry of the lumbar flexion and both chronic pain self-efficacy ($r = -0.438$; $p = 0.02$) and kinesthetic MIQ ($r = -0.476$; $p = 0.011$).

For the AS group, a moderate negative correlation was found between pain self-efficacy and execution chronometry of the TUG ($r = -0.489$; $p = 0.008$). The kinesthetic MIQ correlated moderately with the MI chronometry of the lumbar flexion ($r = 0.468$; $p = 0.012$). Lastly, moderate positive correlations were found for the visual MIQ chronometry and the execution chronometry of lumbar flexion ($r = 0.405$; $p = 0.032$).

3.5. *Regression analyses*

In the multiple linear regression models for the criterion variables MI lumbar flexion chronometry and execution lumbar flexion chronometry in patients with NSCLBP, we discovered that kinesthetic MI and self-efficacy for chronic pain served as predictors for MI chronometry, accounting for 41 % of the variance, with the disability variable being excluded from this model. For execution chronometry, the predictive variable was disability, explaining 32 % of the variance; in this model, the kinesiophobia variable was excluded. The VIF analysis revealed that both models exhibited very low multicollinearity, achieving a value less than 2. This suggests that the predictor variables are not strongly interrelated, indicating that each predictor variable exerts an independent effect on the criterion variable. Statistics related to the regression analyses are presented in Table 5.

4. Discussion

This study focused on evaluating the relationship between MI and sensorimotor function in individuals with NSCLBP. The primary goal was to analyze the temporal congruence between imagined and executed movements. The results point to a temporal incongruence in the NSCLBP group both with the lumbar flexion movement and the TUG. Patients with NSCLBP performed the mental task of both movements significantly faster than they execute the motor gesture. We can hypothesize that these findings are due to central processing changes that may be hindering the ability to perform an adequate, complete, and synchronous imagery process, reflecting a conflict in the capacity to generate images, in terms of accuracy when generating motor images, motivated by pain. Wong et al. (2013) argue that execution, perception, and imagination of action depend on similar neural codes (Wong et al., 2013). Indeed, several authors have suggested that people with motor disorders or pain have difficulties in mentally simulating movements accurately (Pijnenburg et al., 2015; Scandola et al., 2021; Wajda et al., 2021; Wang et al., 2019). In this sense, Vrana et al., (2015) point out differences in cortical activity during MI in people with NSCLBP, suggesting reorganizations in the sensorimotor network. The findings of Vrana et al., (2015) determine that after MI intervention, subjects with NSCLBP showed decreased activity of the supplementary motor area, reduced efficiency of anticipatory postural adjustment systems, reduced

Table 2
Comparative analysis between groups with respect to main variables, including temporal congruence.

Measures	Group	Mean ± SD		Difference of means (95 % CI); Effect size (d)
Lumbar flexion		**Imagery_chronometry**	**Execution_chronometry**	**Imagery-execution**
	NSCLBP_group	2.59 ± 0.1.11	3.20 ± 1.98	−0.61 (−1.1 to −0.12)*; $d = 0.38$
	Asymptomatic_group	1.93 ± 0.64	2.14 ± 0.61	−0.21 (−0.7 to 0.27); $d = 0.33$
Difference of means (95 % CI); Effect size (d)	NSCLBP_group vs Asymptomatic_group	0.66 (0.17 to 1.15)*; $d = 0.72$	1.06 (0.28 to 1.85)*; $d = 0.72$	
		Imagery_chronometry	**Execution_chronometry**	**Imagery-execution**
Timed_Up_and_Go	NSCLBP_group	4.30 ± 1.73	7.84 ± 1.58	−3.54 (−4.07 to −3.01)**; $d = 2.14$
	Asymptomatic_group	4.43 ± 1.41	7.41 ± 1.22	−2.98 (−3.50 to −2.46)**; $d = 2.26$
Difference of means (95 % CI); Effect size (d)	NSCLBP_group vs Asymptomatic_group	−0.14 (−0.99 to 0.72); $d = 0.08$	0.42 (−0.34 to 1.19); $d = 0.30$	

*$p < 0.05$; ** $p < 0.001$. SD: Standard deviation; NSCLBP: nonspecific chronic low back pain.

Table 3
Descriptive and comparative analysis between groups for sensorimotor and psychological variables.

Measures	NSCLBP_group (n = 28)	Asymptomatic_group (n = 28)	Difference of means (95 % CI); Effect size (d)
Kinesiophobia	28.32 ± 8.81	21 ± 5.86	7.32 (3.31 to 11.33)*; d = 0.97
Fear_of_activity_subscale	17.32 ± 6.56	12.39 ± 3.55	4.92 (2.2 to 7.76)**; d = 0.93
Fear_of_Harm_Subscale	11.0 ± 2.99	9 ± 2.42	2.0 (0.54 to 3.46)*; d = 0.73
Chronic pain self-efficacy	137.18 ± 29.74	157.75 ± 18.66	−20.57 (−33.87 to −7.26)**; d = -0.82
Pain_Management_Subscale	25.18 ± 7.7	29.46 ± 6.91	−4.28 (−8.20 to −0.36)*; d = -0.58
Physical_Function_Subscale	56.75 ± 12.89	63.64 ± 5.82	−6.89 (−12.25 to −1.53)*; d = -0.69
Coping_Strategies_Subscale	55.57 ± 14.51	64.64 ± 10.72	−9.07 (−15.91 to −2.22)*; d = -0.71
IPAQ_METS	1341.52 ± 591.07	1992.78 ± 1180.05	−651.26 (−1196.82 to −105.70)*; d = -0.68
MIQ-R_K	21.79 ± 4.02	25.21 ± 2.97	−3.42 (−5.32 to −1.53)**; d = -0.97
MIQ-R_K Chronometry	11.33 ± 4.07	9.68 ± 3.03	1.65 (−0.27 to 3.57); d = 0.46
MIQ-R_V	22.68 ± 4.24	25.68 ± 2.83	−3 (−4.93 to −1.07)*; d = -0.83
MIQ-R_V Chronometry	11.43 ± 3.64	9.53 ± 2.88	1.8 (0.13 to 3.65)*; d = -0.57

Values are presented as mean ± standard deviation or number (%). *p < 0.05; ** p < 0.001; NSCLBP: nonspecific chronic low back pain; IPAQ_METS: Physical activity questionnaire; PA: Physical activity; MIQ-R: Movement Imagery Questionnaire Revised. MIQ-R_K, kinaesthetic subscale scores of the MIQ-R; MIQ-R_V, visual subscale scores of the MIQ-R.

Table 4
Correlation analysis examining the bivariate relationships for motor imagery chronometry and execution chronometry of the lumbar flexion movement and TUG test.

		MI_Chronometry_LF	Execution_Chronometry_LF	mi_Chronometry_TUG	Execution_Chronometry_TUG
Pain Intensity	*NSCLBP*	0.041	0.157	−0.026	0.007
	Asymptomatic	–	–	–	–
Disability	*NSCLBP*	**0.431***	**0.585****	0.046	0.108
	Asymptomatic	–	–	–	–
Kinesiophobia	*NSCLBP*	0.328	**0.576****	0.084	0.154
	Asymptomatic	0.284	0.245	0.295	0.306
Chronic pain self-efficacy	*NSCLBP*	**−0.438***	−0.229	−0.305	−0.141
	Asymptomatic	−0.194	**−0.386***	−0.207	**−0.489****
IPAQ (METS)	*NSCLBP*	−0.057	−0.233	0.162	0.166
	Asymptomatic	−0.302	−0.259	−0.081	−0.037
MIQ-R_K	*NSCLBP*	**−0.476***	−0.313	−0.019	−0.219
	Asymptomatic	**0.468***	0.142	**0.399***	0.061
MIQ-R_K Chronometry	*NSCLBP*	0.074	**−0.125**	0.309	0.219
	Asymptomatic	0.186	**0.395***	−0.109	0.053
MIQ-R_V	*NSCLBP*	−0.109	−0.068	−0.138	−0.263
	Asymptomatic	**0.392***	0.117	**0.391***	−0.030
MIQ-R_v Chronometry	*NSCLBP*	0.136	0.071	0.292	0.264
	Asymptomatic	0.240	**0.405***	−0.071	0.066

*p < 0.05; ** p < 0.01. NSCLBP: nonspecific chronic low back pain; MI, Motor Imagery; LF, Lumbar Flexion; TUG, Timed Up and Go; IPAQ_METS, Physical activity questionnaire; PA, Physical activity; MIQ-R, Movement Imagery Questionnaire Revised. MIQ-R_K, kinesthetic subscale scores of the MIQ-R; MIQ-R_V, visual subscale scores of the MIQ-R.

Table 5
Regression model for motor imagery and execution chronometry of lumbar flexion movement in patients with NSCLBP.

Criterion Variable: MI lumbar flexion chronometry				
General Model				
$R^2 = 0.454$; Adjusted $R^2 = 0.41$; F = 10.385; p<.001				
Predictor Variables	**Regression Coefficient (β)**	**Standardized Coefficient (β)**	**P Value**	**VIF**
MIQ-R_K	−0.142	−0.513	0.002	1.006
Chronic pain self-efficacy	−0.078	−0.479	0.003	1.006
Excluded Variables				
Disability	–	0.078	0.683	1.557
Criterion Variable: Execution chronometry of lumbar flexion				
General Model				
$R^2 = 0.342$; Adjusted $R^2 = 0.317$; F = 13.534; p<.001				
Predictor Variables	**Regression Coefficient (β)**	**Standardized Coefficient (β)**	**P Value**	**VIF**
Disability	0.227	0.585	0.001	1
Excluded Variables				
Kinesiophobia	–	0.309	0.219	2.431

MI, Motor Imagery; MIQ-R_K, kinesthetic subscale scores of the Movement Imagery Questionnaire Revised.

activity of the superior temporal region and possible hyperexcitability of the sensorimotor network implying a deficit in the integration of sensory inputs (Vrana et al., 2015). Furthermore, in this line, La Touche et al., (2019) documented difficulties in generating both kinesthetic and visual motor imagery specifically in patients with NSCLBP (La Touche et al., 2019).

Our data align with previous studies indicating altered neuronal processing in situations of low back pain (Pijnenburg et al., 2015; Tsao et al., 2010). In this line, studies carried out with functional magnetic resonance imaging in patients with CLBP show that there is an alteration in the default mode network, thus implying a connection deficit between cortical areas involved in the planning of movement (Baliki et al., 2008; Tagliazucchi et al., 2010). Furthermore, the available scientific evidence determines that patients with chronic pain present a cortical reorganization in several sensorimotor areas such as the middle frontal gyrus, left postcentral gyrus and cerebellum (Mantini et al., 2007; Moulton et al., 2010; Tagliazucchi et al., 2010). Previous studies suggest that patients with NSCLBP also present a lower density of grey matter and a functional reorganization of the primary somatosensory cortex, which has been related to greater pain intensity, altered postural control and tactile sensitivity(Baliki et al., 2012; Gustin et al., 2012; Kong et al., 2013).

In line with our results, Pijnenburg et al., 2015 demonstrated in subjects with CLBD that decreased functional connectivity between the left precentral gyrus and lobes IV and V of the cerebellum, both areas involved in sensorimotor integration, were associated with longer Sit-to-Sit test performance time (Pijnenburg et al., 2015). Related to this finding, a 2014 study showed that impaired connection between areas involved in such integration could also explain a decrease in performance in bilateral visuomotor tasks (Solesio-Jofre et al., 2014).

An interesting finding of the present study was that AS also present temporal incongruence, though only for the TUG test and not for the flexion movement. Generally, temporal congruence between imagined and executed movements is assumed to exist for AS, as corroborated by several studies (Calmels & Fournier, 2001; Munzert, 2002; Wajda et al., 2021; Wang et al., 2019). However, other studies speak of differences in the ability to imagine motivated by the simplicity or complexity and familiarity with the gesture, or by the automation of the movement being tested (Calmels & Fournier, 2001; Guillot & Collet, 2005; Paris-Alemany et al., 2019).

In our AS, the time spent executing the TUG was greater than that spent imagining it, thereby underestimating the time needed to perform it physically. In situations of greater familiarity with the movement or automated movements, the synchrony could be altered by a matter of learning and perfection of the movement that leads to brain efficiency (Ladda et al., 2021). On the other hand, the fact that the movement is complex or unusual could also generate a temporal asynchrony due to excess time spent in imagery, although it is true this result in turn may depend and vary according to how familiar the participant is with physical activity in general (Calmels & Fournier, 2001; Guillot & Collet, 2005).

At the neurophysiological level, this result could have the following justification. Human movement is a cortical expression (Touche, 2019), which is planned in secondary motor areas such as the premotor cortex or the supplementary motor area before the signal is sent to the primary motor cortex, and from there, travels to the muscle effectors through the corticospinal pathway (Heckman & Enoka, 2004) The premotor cortex receives predominantly nonconscious proprioceptive cerebellar information (Perea Bartolomé & Ladera Fernández, 2004). In addition, the cerebellum participates extensively in the motor learning process by defining the automatic sequences associated with specific motor gestures (De Zeeuw & Ten Brinke, 2015; Thach, 1998). Cerebellar activity and its communication with the premotor cortex work in automatic mode, where the motor program is activated, and a set of automatisms is set in motion (VanMeter et al., 1995). In addition, the prefrontal cortex also participates in the planning and adjustment of voluntary movement because it communicates with the premotor cortex (and this, in turn, with the primary motor cortex) (Exner et al., 2002; Jueptner et al., 1997; Ono et al., 2015). Cognitive influences can modify the motor plan generated by automatic mechanisms coming from the cerebellum (Exner et al., 2002). This occurs when a more complex motor gesture is to be planned. Due to the phenomenon of neurophysiological convergence between the imagination of a motor gesture and its execution, a greater complexity will imply a greater involvement of the prefrontal cortex, causing a reduction of the automatisms provided by the cerebellar activity, which will probably be accompanied by a longer MI time. Very learned movements and where the person is very familiar, probably require less activity of the prefrontal cortex, as well as a shorter planning time of the voluntary movement because all this information will be given by automatisms mediated by the activity of the cerebellar structure.

As has been observed previously, athletes or dancers very familiar with the movement have a great ability to generate motor images, using shorter times or even voluntarily modifying the time spent in the imagining process, this is understood to be a product of their super specialization with the movement and the practice of MI (Calmels & Fournier, 2001; Guillot & Collet, 2005).

The flexion movement is simple, and in AS, we expect there to be synchrony as has occurred. However, in patients with NSCLBP, the flexion movement occurred asynchronously, performing the imagery process faster and the real movement slower. These results could be explained by the influence of pain itself and aspects of fear and avoidance of movement, which may be interfering both in the mental process and in the execution of the movement. We could hypothesize that the temporal asynchrony in the NSCLBP group could be due, in part, to the patients' avoidance of certain movements due to pain, including lumbar flexion, exacerbating the differences observed in MI chronometry. The analysis of the TSK-11 subscales revealed that both avoidance and fear of harm behaviors influence the temporal asynchrony in NSCLBP patients. Avoidance behaviors, in particular, showed a stronger contribution to the differences between imagined and executed movements, as evidenced by the significant interaction between time and the avoidance subscale. Fear of harm also played a role, although to a lesser extent. These findings suggest that addressing fear-avoidance behaviors in patients with NSCLBP may be crucial in improving motor imagery congruence and movement execution. These results align with the broader literature, which suggests that fear of movement can exacerbate pain-related disability in chronic pain populations.

In NSCLBP patients, the process of forming mental images has turned out to be faster, however, in this group, the ability to imagine is altered according to the data obtained in the MIQ-R. On the other hand, patients perform the flexion movement significantly slower, probably conditioned by the fear of performing that specific lumbar movement.

As we have previously commented, the presence of pain, as well as high levels of fear-avoidance would be the arguments for the findings found in patients with CLBP. These arguments have a neurophysiological explanation that could justify it. The key is redundant sensory information via the thalamus (Behrens et al., 2003; Chouinard & Paus, 2006). The premotor cortex receives processed somatosensory information from the somatosensory cortex (which has previously passed through the thalamic structure before reaching the cerebral cortex). However, in addition to this information, the premotor cortex also receives unprocessed somatosensory information directly from the thalamus. Thus, there is a redundant communication via the thalamus that highlights the importance of somatosensory information in the planning process of voluntary movement (Behrens et al., 2003; Chouinard & Paus, 2006).

This implies that in the presence of a sensory disturbance (sustained pain, allodynia, hyperalgesia, etc.) the construction of the movement is likely to be altered due to the quality of the sensory information (Hodges & Tucker, 2011; W. Kim et al., 2017; Uremović et al., 2007), which may explain the findings regarding the loss of temporal congruency. In addition, the supplementary motor area, which is largely involved in the planning of sequenced voluntary movement, also receives information from thalamic structures, and in turn, receives subcortical information from the basal ganglia (Ferrandez et al., 2003; Iansek et al., 1995). It is in the basal ganglia where the modulation circuits are carried out and this feedback to the supplementary motor area to modify some movement parameters, such as intensity, frequency or directly inhibiting or not the participation of other brain structures (Iansek et al., 1995). The ganglia of the base are made up of four loops (motor, limbic, oculomotor and cognitive). Highlighting the limbic loop, it is responsible for the involvement of emotions related to voluntary movement where, therefore, the motivational-affective component and the context of movement are widely related (Lanciego et al., 2012). The corticospinal pathway presents a neuroanatomical relationship with the limbic system, via the basal ganglia. Probably, an-input of painful somatosensory information, as well as a high presence of symptoms compatible with fear and avoidance may affect the planning of voluntary movement, which could secondarily affect the subsequent ability to imagine it, losing temporal congruence in all the movements evaluated. The only thing that would remain to be answered is why patients with CLBP underestimated MI time. We believe it is due to the presence of the fear itself. CLBP patients with movement-related fear would seem to pay excessive attention to possible threats from the environment, which would make it more difficult to focus their attention on other tasks such as the cognitive task of imagining itself, making it more imprecise and shorter, i.e., losing precision and imagination-execution synchronization (Crombez et al., 1998).

On the other hand, it seems that the accuracy and speed at which imagined tasks are performed are closely related to cognitive performance and more specifically to memory. Those people who have a greater processing capacity are capable of forming better mental images (T. Kim et al., 2019). This may be related to our results since although these variables have not been evaluated in our study, the available scientific evidence shows that patients with NSCLBP may present alterations in cognitive variables such as memory, attention, and executive function, in addition to alteration of functional variables (Corti et al., 2021; da Silva et al., 2018; Mi et al., 2018; Rabey et al., 2017; Simon et al., 2016). A few years ago, Cuenca-Martínez et al. conducted a neurophysiological hypothesis regarding the functioning of movement representation techniques at the cognitive level. Specifically, the ability to imagine is closely related to the functioning of working memory. A more efficient functioning of working memory could increase the ability to collect the information provided, as well as its consolidation to long-term memory. This is because the construction of mental images through MI is fed by the activity of working memory, and subsequently, of the episodic buffer. The episodic buffer collects information to feed the working memory from the consolidated memory, i.e., episodic, semantic and, of course, perceptual-motor memory. It is therefore that MI requires predominantly conscious strategies for the process of creating mental images of movement (Cuenca-Martínez et al., 2020). All this could explain the results obtained in our study.

Moreover, the findings of this study suggest that there are differences between the NSCLBP group and the AS group regarding lumbar flexion movement, so that patients take longer to imagine and move slower. In this line, there is previous evidence that NSCLBP patients have a lower ability to imagine and also take more time for the mental process than AS (La Touche et al., 2019). However, these differences are not observed in the TUG test, indicating that this sequence of movements is imagined similarly by both groups, and also performed similarly by both groups in terms of time spent.

These different results could be influenced by behavioral aspects of avoidance and disability when regarding the flexion movement which in perceived as a threatening gesture, as we have previously indicated; in patients with NSCLBP, the avoidance of movement due to pain could contribute to these results (Hashmi et al., 2013). This factor could be directly impacting the imagination, planning, and execution of said movement, thus causing an alteration in the capacity to imagine. The regression model analysis revealed that disability, rather than kinesiophobia, was the primary predictor of lumbar flexion execution chronometry, explaining 32 % of the variance. This finding suggests that the reduced ability to perform the movement is more closely linked to the level of disability experienced by NSCLBP patients, rather than the fear of movement itself. While kinesiophobia is often associated with avoidance behaviors, in this instance, it appears that the physical limitations imposed by disability played a more significant role in the observed temporal asynchrony. This highlights the importance of addressing physical limitations and functional disability when developing interventions to improve movement performance in patients with NSCLBP.

Regarding associations, we have found that the more lumbar disability patients present, the longer they take to imagine the flexion movement, and this is related to having a lower ability to imagine kinesthetically. In fact, the capacity for constructing kinesthetic motor images is more complex than the visual one. Humans tend to use visual imagery processes more easily; however, kinesthetic imagery is more complex and requires training (Olsson et al., 2008). It has been observed that dancers and athletes familiar with the movement use kinesthetic imagery more easily, and moreover, the combination of both types of imagery is much more efficient for their training since different brain areas are activated (Bläsing et al., 2012; Filgueiras et al., 2017; Ridderinkhof & Brass, 2015).

Finally, it is worth mentioning that in AS, positive associations were found between the level of self-efficacy and execution time, performing the movement faster. On the other hand, the level of physical activity is related to shorter imagination times, considering that they performed the movement without having a previous reference of its duration, these healthy participants probably underestimated the time they required to perform it, and the higher the level of physical activity, the faster was the process of imagining. Studies conducted on athletes indicate that in this type of population, the imagining process can be fast if the movement is simple (Calmels & Fournier, 2001). Moreover, in this group, it was observed that a longer time spent in motor imagery of the MIQ was associated with longer execution time of the flexion movement.

4.1. Clinical Implications and future research Directions

Integrating current findings with existing literature, this study addresses the temporal congruence between imagined and executed movements in individuals with NSCLBP, proposing an innovative framework for the incorporation of MI into rehabilitation programs. Given the observed variability in temporal congruence, a personalized approach to MI practices is suggested, which could significantly benefit the rehabilitation of NSCLBP patients. This proposal is grounded in adapting MI interventions to specifically address deficits in motor planning and execution, an approach supported by previous studies that highlighted the impact of cognitive dysfunction on MI capacity (Geiger et al., 2017).

The significance of comprehensive cognitive assessment in the diagnosis and treatment of NSCLBP patients becomes evident, suggesting that cognitive impairment may affect the efficacy of MI. This perspective aligns with research exploring the modulation of temporal congruence by cognitive factors, including attention and executive function (Geiger et al., 2017). Moreover, considering body position and MI strategies during rehabilitation, inspired by Beauchet et al. (2018), suggests a path toward more personalized treatments that can optimize temporal congruence and, hence, the effectiveness of MI in this population (Beauchet et al., 2018).

Looking forward, the necessity for longitudinal studies to better understand the dynamics of MI capacity and its relationship with physical rehabilitation outcomes is evident. Incorporating objective measures to assess the quality of MI, such as neuroimaging techniques and physiological markers, could provide a more detailed understanding of the neural correlates of successful MI interventions in NSCLBP (Marchesotti et al., 2016).

The role of music and rhythmic cues as facilitators of MI synchronization, examined by Debarnot and Guillot (2014) (Debarnot & Guillot, 2014), along with the impact of visual and auditory distractions on MI quality (Hohmann et al., 2016), emphasizes the importance of considering environmental factors in MI practice. These findings suggest unexplored pathways to enhance temporal accuracy and the effectiveness of rehabilitation interventions for NSCLBP patients.

Exploring how different locomotor tasks affect MI in NSCLBP patients could lead to the development of more targeted and effective rehabilitation strategies, a direction suggested by Fusco et al. (2014) (Fusco et al., 2014). This study underscores the importance of carefully integrating MI into NSCLBP rehabilitation, urging future research that combines clinical practice with advanced scientific inquiry to offer more effective and personalized interventions for individuals with NSCLBP.

4.2. Limitations

This study, while contributing valuable insights into the temporal congruence between imagined and executed movements in patients with NSCLBP, possesses several limitations that warrant consideration for the interpretation and generalization of its findings.

Firstly, the cross-sectional design of this research precludes the determination of causality between NSCLBP and the observed discrepancies in motor imagery and execution. Longitudinal studies would be instrumental in elucidating the directionality and dynamics of these relationships over time, potentially unveiling the progression of motor imagery discrepancies as NSCLBP evolves.

Secondly, the study's reliance on self-reported and timed measures for assessing motor imagery and execution introduces potential biases and inaccuracies. Objective measurements, such as neuroimaging techniques or motion capture technologies, could provide a more nuanced and precise understanding of the neural and biomechanical underpinnings of temporal congruence in this population. Assessing the vividness of motor imagery to examine in greater detail whether the rapid imagery process is due to poor quality of image formation. In this context, it might also be interesting to include an objective metric for assessing the activation of the autonomic nervous system (ANS). Previous studies have demonstrated that during the process of imagination, there is activation of the ANS, which is manifested by an increase in heart rate, respiratory rate, and electrodermal skin activity (Collet et al., 2013).

The study's focus on a specific subset of the NSCLBP population, defined by particular inclusion criteria, may also limit the applicability of its results. The exclusion of patients with certain comorbidities or those outside the specified age range could overlook the variability in motor imagery and execution across different stages or types of back pain.

Additionally, while this study integrates psychological variables such as fear of movement and self-efficacy, it does not encompass the full spectrum of cognitive factors that could influence motor imagery and execution. Aspects such as attention, memory, and executive function, which are known to interact with chronic pain, were not examined. Incorporating a comprehensive assessment of cognitive and psychological dimensions could enrich the understanding of their roles in motor imagery discrepancies among NSCLBP patients.

5. Conclusions

This study reveals significant temporal incongruence in MI and execution in NSCLBP patients, suggesting impaired motor planning and execution. Notably, NSCLBP patients imagined movements faster than execution, indicating a possible disruption in the neural coding system that aligns MI with actual movement, potentially linked to sensorimotor network reorganizations. The presence of temporal incongruence in AS for complex tasks like the TUG test further underscores the influence of task complexity, familiarity, and movement automation on MI accuracy. These findings highlight the intricate relationship between cognitive function, MI, and motor execution in NSCLBP, suggesting that cognitive impairments may underpin the observed discrepancies. Incorporating personalized motor imagery strategies into rehabilitation for NSCLBP, considering cognitive and functional assessments, may enhance treatment efficacy. Future research should focus on longitudinal studies and incorporate objective measures to deepen understanding of the neural mechanisms underlying MI discrepancies in NSCLBP, potentially leading to more effective, tailored rehabilitation interventions.

CRediT authorship contribution statement

Manuel Estradera-Bel: Writing – review & editing, Writing – original draft, Investigation. **Roy La Touche:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Diego Pro-Marín:** Writing – review & editing, Writing – original draft, Investigation. **Ferran Cuenca-Martínez:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Alba Paris-Alemany:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mónica Grande-Alonso:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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