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Agathe Bilhaut, Mathieu Ménard, Olivier Roze, Armel Crétual, Anne-Hélène Olivier. Locomotion behavior of chronic Non-Specific Low Back Pain (cNSLBP) participants while walking through apertures. *Gait & Posture*, 2023, 104, pp.140 - 146. 10.1016/j.gaitpost.2023.06.015 . hal-04169296

**HAL Id: hal-04169296**

<https://inria.hal.science/hal-04169296v1>

Submitted on 24 Jul 2023

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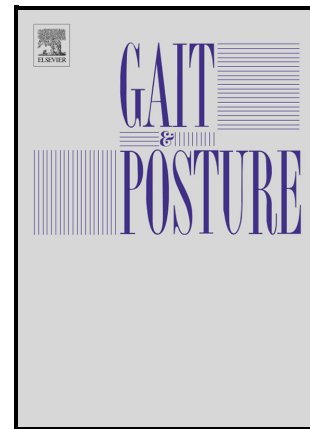


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## Journal Pre-proof

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PII: S0966-6362(23)00166-2

DOI: <https://doi.org/10.1016/j.gaitpost.2023.06.015>

Reference: GAIPOS9304

To appear in: *Gait & Posture*

Received date: 5 February 2023

Revised date: 24 May 2023

Accepted date: 21 June 2023

Please cite this article as: Agathe Bilhaut, Mathieu Ménard, Olivier Roze, Armel Crétual and Anne-Hélène Olivier, Title: Locomotion behavior of chronic Non-Specific Low Back Pain (cNSLBP) participants while walking through apertures, *Gait & Posture*, (2023) doi:<https://doi.org/10.1016/j.gaitpost.2023.06.015>

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**Title: Locomotion behavior of chronic Non-Specific Low Back Pain (cNSLBP) participants while walking through apertures**

Agathe Bilhaut <sup>a,\*</sup>, Mathieu Ménard <sup>a,b</sup>, Olivier Roze <sup>c</sup>, Armel Crétual <sup>d</sup>, Anne-Hélène Olivier <sup>d</sup>

<sup>a</sup> Laboratoire Mouvement Sport Santé (M2S), Université Rennes 2, Campus Rennes Atalante Ker-Lann, 14 Avenue Robert Schuman, 35170, Bruz, France

<sup>b</sup> Institut d'Ostéopathie de Rennes - Bretagne (IO-RB), Campus Rennes Atalante Ker-Lann, 50 Rue Blaise Pascal, 35170 Bruz, France

<sup>c</sup> Clinique Mutualiste la Sagesse, 4 place Saint Guénolé, 35000, Rennes, France

<sup>d</sup> Univ Rennes, Inria, CNRS, IRISA, M2S, F-35000 Rennes, France

\*Correspondence to : Laboratoire Mouvement Sport Santé (M2S), Université Rennes 2, 14 Avenue Robert Schuman, 35170, Bruz, France. [agathe.bilhaut@univ-rennes2.fr](mailto:agathe.bilhaut@univ-rennes2.fr)

**Abstract**

*Background:*

Chronic Non-Specific Low Back Pain (cNSLBP) has been identified as one of the leading global causes of disability and is characterized by symptoms without clear patho-anatomical origin. The majority of clinical trials assess cNSLBP using scales or questionnaires, reporting an influence of cognitive, emotional and behavioral factors. However, few studies have explored the effect of chronic pain in daily life tasks such as walking and avoiding obstacles, which involves perceptual-motor processes to interact with the environment.

*Research question:*

Are action strategies in a horizontal aperture crossing paradigm affected by cNSLBP and which factors influence these decisions ?

*Methods:*

15 asymptomatic adults (AA) and 15 cNSLBP participants walked along a 14 m long path, crossing through apertures ranging from 0.9 to 1.8 times their shoulder width. Their movement

was measured using the Qualisys system, and pain perception was evaluated by self-administered questionnaires.

*Results:*

The cNSLBP participants stopped rotating their shoulders for a smaller aperture relative to their shoulder width (1.18) than the AA participants (1.33). In addition, these participants walked slower, which gave them more time to make the movement adaptations necessary to cross the aperture. No correlation was found between the variables related to pain perception and the critical point but the levels of pain were low with a small variability.

*Significance:*

This study shows that during a horizontal aperture crossing task requiring shoulder rotation to pass through small apertures, cNSLBP participants appear to exhibit a riskier adaptive strategy than AA participants by minimizing rotations that could induce pain. This task thus makes it possible to discriminate between cNSLBP participants and pain-free participants without measuring the level of pain. The identification number registered in the clinical trials is NCT05337995.

**Keys words**

Low back pain; Chronic pain; Human locomotion; Affordances; Actions; Kinematics

**Funding:** Université Rennes 2, Rennes, France

**Introduction**

Non-specific low back pain is one of the most common pain worldwide and a leading cause of disability [1]. It is characterized by pain or discomfort below the costal margin and above the lower gluteal folds, with or without pain in either leg [2] and whose pathoanatomical origin cannot be determined [3–5]. This pain is considered chronic if it lasts more than 12 weeks [6].

Self-administered scales and questionnaires are commonly used to assess cNSLBP in clinical trials [7]. Inexpensive, quick and easy to administer, these standardized instruments have been developed and validated to assess and collect the components influencing pain perception (sensory-discriminative, emotional, cognitive and behavioral) [8]. Although they are of primary interest, they do not provide a comprehensive view of the assessment of these participants. In particular, they do not take into account interaction with the environment, such as activities of daily living, which involve perceptual-motor processes.

One of the daily tasks used to discriminate cNSLBP from an asymptomatic population is straight-line walking without any obstacle to interact with. Some authors showed differences in kinematic and dynamic parameters, in particular walking speed, stride duration, rotational amplitudes of the lumbopelvic system and ground reaction forces [9,10]. Others authors qualify these results, in particular when the pain intensity is low [11]. However, the study of locomotion should not be limited to walking in a straight line in an empty environment, as walkers must constantly respond to the environmental demand by adapting their actions to avoid obstacles [12]. This has been widely developed by the ecological approach to perception and action with the concept of affordance [13]. Perception is not only related to the characteristics of the environment but also to the actor-environment relationship. This relation offers opportunities for action to the individual that would be expressed through a scaling of their anthropometric dimensions but also of their functional capacities in a specific environment [14–19].

Hence, one of the experimental paradigms widely used to study the perceptual-motor coordination involved during locomotion in the presence of obstacles, either for healthy young adults [20] or for specific populations (children, elderly people, dyspraxic adults) [14,19,21], is that of obstructed walking. This paradigm allows to investigate the adequacy between the properties of the environment and the individual, especially by identifying critical points where a transition phase is necessary to produce a new action [20]. When passing through a horizontal

aperture, similar to a doorway, the critical point corresponds to the aperture width for which the participants change their mode of action, i.e. turn their shoulders to pass through the door, whereas for bigger widths they pass through without turning them [14–20]. In asymptomatic adults, these adaptive strategies are invariant: the angle of shoulder rotation depends on the relative size ratio between shoulders and aperture widths (SA ratio), ranging from 1.3 to 1.4 according to the authors [15,17,18].

The paradigm of passing through an aperture has never been studied in cNSLBP population, although it could allow us to understand the effect of chronic pain on movement strategies in an ecological context.

The primary objective was to determine whether cNSLBP modifies the critical point values usually described in asymptomatic populations during a locomotor task of passing through a horizontal aperture. Secondary objective is two-fold: (2-a) to examine kinematic gait variables characteristic of participants and (2-b) to assess the influence of pain perception variables on the observed critical point values.

The main hypothesis is that cNSLBP participants will have a lower critical point than asymptomatic adults because of shoulder rotation limitation due to pain, and therefore engage themselves in a riskier strategy. Regarding gait kinematics (2-a), the hypothesis is that cNSLBP participants turn the shoulders less, walk more slowly and have greater body oscillations which would partly explain the strategy adopted when passing the obstacle. Finally, concerning pain perception (2-b), the hypothesis is that the locomotor strategies adopted by the cNSLBP participants are partly correlated to variables related to pain perception (sensory-discriminative, emotional and behavioral).

## **Methods**

### *Participants*

Fifteen cNSLBP adults ( $41.9 \pm 14.1$  years, 5 females) and fifteen asymptomatic adults (AA,  $43.7 \pm 14.9$  years, 9 females) volunteered and provided written consent. The cNSLBP adults had to suffer from low back pain for more than 12 weeks and at least 4 days a week, without analgesic treatments other than stable. Individuals who were pregnant or breastfeeding, had uncorrectable visual impairments, cognitive difficulties (MMSE [22] < 28), psychological, neurological or any warning sign pointing to an underlying pathology requiring specific and/or urgent treatment were not allowed to participate. In addition, the AA group shouldn't have ongoing chronic pain or a history of significant chronic pain ( $\geq 4/10$  on Visual Analog Scale (VAS) for at least 6 months) and pathologies affecting walking or posture. This study was approved by the Committee for the Protection of Individuals Sud-Ouest et Outre-Mer 1 (CPP SOOM1), France.

#### *Experimental Design*

Two obstacles (Fig.1.) constituting the aperture to be crossed, were placed in a gymnasium (20\*30m). The origin of the reference frame is set at the middle of the aperture, x axis being the one along which participants walked. Their trajectory was recorded using an opto-electronic Qualisys system (23 cameras, 200Hz). 9 reflective markers were placed on participants using standardized anatomical landmarks: seventh cervical (C7), both glenohumeral (GH) joints, anterior and posterior superior iliac spines (ASIS and PSIS, respectively), and external ankle malleoli.

#### *Protocol*

First, participants completed self-reports on anxiety and depression (Hospital Anxiety Depression Scale, HADS [23]) and on quality of life (EuroQol 5 Dimension, EQ-5D [24]). In the cNSLBP group, pain perception was assessed using its various components described in Table 1.

Then, participants performed the walking experiment. They were asked to perform 60 trials by walking in a straight line for 14m at their comfort speed. Participants started with 3 trials with no objects in the path (baseline), then they performed the horizontal opening crossing task: at the middle of the path they had to go through the aperture of varying widths (Fig.1.). Participants performed 3 blocks of 19 trials corresponding to aperture sizes ranging from 0.9 to 1.8 times their shoulders width (increments of 0.05), presented in a random order. After each of the 3 blocks, cNSLBP participants were asked to rate their pain on the VAS.

#### *Data analysis*

To remove oscillations due to stepping activity, data were filtered using a 10 Hz butterworth low pass filter. Shoulder and aperture widths were calculated using the horizontal position of both GH and door markers respectively. Separate kinematic measures were taken for the approach phase, corresponding to the time between the 2<sup>nd</sup> and 4<sup>th</sup> second after the movement starts (*approach*), and the crossing time which refers to the moment when the participant walks through the aperture (*tcross*) (Fig.2.; NB: a similar method was adopted by Wilmut et al. [18,19]).

We then computed the following kinematic variables:

#### Walking speed

Participant's horizontal position of Centre Of Mass (COM) was approximated as the middle of the right and left GH and C7. Instantaneous walking speed was calculated as the first time derivative of COM anteroposterior position.

*Approach speed (m/s)* describes the average movement speed during *approach*.

*Crossing speed (m/s)* refers to the participant's speed at *tcross*.

#### Shoulder rotation

The shoulder rotation of each participant was calculated from the horizontal coordinates of the two GHs for the unobstructed straight lines and the experimental trials. The angle was defined



in the horizontal plane between the GH line and the instantaneous walking direction. We used the absolute value of this angle, i.e. not differentiating which shoulder is the first to enter the aperture. Indeed, we did not observe consistent strategies between participants, who rotated their shoulders to the left or to the right.

*Approach shoulder rotation* ( $^{\circ}$ ) is the mean yaw rotation angle of the shoulders during approach in experimental and baseline trials.

*Crossing shoulder rotation* ( $^{\circ}$ ) is the yaw rotation angle of the shoulders at *tcross*.

#### Critical point

*The critical point* corresponds to the SA ratio at which individuals change their mode of action, i.e. have turned their shoulders to successfully pass the obstacle. The individual critical point of each participant was determined by performing a linear bi-regression with the yaw rotation angle at *tcross* as a function of the width of the opening, where the critical point corresponds to intersection between the two regression lines.

#### Phase shift between the scapular and pelvic rotation

The difference in scapular and pelvic yaw rotation angles in the horizontal plane of each participant was calculated from the horizontal coordinates of the two GHs and PSIS for the unobstructed straight line and experimental trials. We used the absolute value of this angle.

*Approach phase shift* ( $^{\circ}$ ) is the mean yaw rotation angle between the scapular and pelvic during *approach* in experimental and baseline trials.

*Crossing phase shift* ( $^{\circ}$ ) is the yaw rotation angle between the scapular and pelvic *at tcross*.

#### Trunk stability

*Trunk stability* was computed as the average amplitude of COM medio-lateral (ML) oscillations both for the unobstructed straight line and experimental trials during *approach*.

#### Statistical analysis

Data analysis was performed using RStudio (Version 4.1.3; RStudio, Inc) and MATLAB (Version R2021b, MathWorks, Natick, USA). Statistical significance was set at  $p < 0.05$ . Normality and homogeneity of variance were assessed using Shapiro-Wilk and Levene tests. Differences between groups for participants' characteristics (age, sex, shoulder width, MMSE, HADS, EQ-5D) and critical points were assessed using student's or welch's t-test according to the conditions of homogeneity of the variance or Wilcoxon rank-sum test and Chi-Squared test. Mixed Anovas followed by pairwise comparisons post-Hoc tests with Bonferroni correction were used to assess the group effect on the SA ratio for walking speed, shoulder rotation angle, phase shift between the scapular and pelvic angles and trunk stability during *approach* and *tcross*. Correlations were made between the scores related to the pain perception questionnaires and the critical point of each cNSLBP participant.

## Results

### Participants' characteristics

Age, sex and shoulder width were not significantly different between the cNSLBP and AA groups. There were no significant differences between groups for MMSE ( $p=0.27$ ), HADS-A ( $p=0.33$ ) and HADS-D ( $p=0.31$ ) scores. However, results showed the AA group (med=1, iqr = 0.09) had a higher quality of life score [ $W=180$ ,  $p=0.00013$ ,  $r=0.73$ ] than the cNSLBP participants (med=0.76, iqr = 0.13) for the EQ-5D (Table 1.).

### Main criterion: Critical point

The critical point was significantly higher in the AA group ( $1.33 \pm 0.15$ ) compared to the cNSLBP group ( $1.18 \pm 0.08$ ) [ $t(22.7) = -3.34$ ,  $p<0.01$ ,  $d = -1.23$ ] (Fig.3.). The coefficient of variation was 0.11 for the AA group and 0.07 for the cNSLBP group.

### Secondary criteria

#### Gait characteristics

Comparison between groups and between SA ratios and straight unobstructed trials during *approach*:

No significant effects of the group ( $p = 0.73$ ,  $p=0.89$ ,  $p = 0.78$ ), SA ratio ( $p = 0.20$ ,  $p=0.69$ ,  $p = 0.18$ ) and interactions ( $p = 0.09$ ,  $p=0.45$ ,  $p = 0.50$ ) were identified for the *shoulder rotation* (Fig.4.b.), *phase shift* (Fig.4.c.) and *trunk stability* during *approach*, respectively. For the *approach speed* (Fig.4.a.), a significant effect of the group [ $F(14,1)=4.83$ ,  $p = 0.045$ ,  $\eta^2=0.243$ ] and no significant effects of SA ratios ( $p=0.135$ ) and interactions ( $p=0.097$ ) were identified. cNSLBP group walked significantly slower than AA group ( $p<0.001$ ).

Comparison between groups and between SA ratios at *tcross*:

All participants successfully passed through all apertures size without colliding. Significant effect of SA ratios ([ $F(252,17)=8.99$ ,  $p < 0.0001$ ,  $\eta^2=0.19$ ], [ $F(252,17)=87.52$ ,  $p < 0.0001$ ,  $\eta^2=0.77$ ]) and no significant effect of the group ( $p=0.06$ ,  $p=0.29$ ) and interaction ( $p=0.89$ ,  $p=0.52$ ) were identified for walking speed (Fig.4.a.) and shoulder rotation (Fig.4.b.) respectively. Specifically, crossing speed increased and crossing shoulder rotations decreased as the size of the aperture increased. When considering phase shift (Fig.4.c.) significant effects of SA ratio and interactions were identified ([ $F(252, 18)=21.54$ ,  $p < 0.0001$ ,  $\eta^2=0.51$ ], [ $F(252, 18)=1.73$ ,  $p < 0.01$ ,  $\eta^2=0.08$ ], respectively). There was a significant effect of SA ratios for AA [ $F(108, 18)=10.3$ ,  $p < 0.0001$ ,  $\eta^2=0.57$ ] and cNSLBP [ $F(144, 18)=11.4$ ,  $p < 0.0001$ ,  $\eta^2=0.43$ ] groups. For both groups, crossing phase shift decreased as the size of the aperture increased.

#### Pain perception

The RMDQ, FABQ, PCS, PIPS and TSK scores are presented in Table 1. No correlation was found between the variables related to pain perception and the critical point.

#### Discussion

The main objective was to determine whether cNSLBP affects participants adaptive locomotion strategies as they interact with the environment. In particular, this study explored the choice of

action modes in a task of walking through apertures, revealed by critical points (i.e horizontal aperture width for which the participants began to turn their shoulders).

#### Critical point

The critical point observed in cNSLBP participants was smaller than in AA participants (respectively 1.18 vs 1.33). In asymptomatic adults this critical point is in line with previous work ranging from 1.3 to 1.4 according to the authors [14,16,17]. Furthermore, the coefficient of variation was lower for cNSLBP participants (0.07) than for AA participants (0.11). This suggests cNSLBP participants used a smaller safety margin to pass the obstacle, as they stopped turning their shoulder for smaller aperture than AA participants, and this behavior was consistent between participants. This strategy could be explained by behavioral and psychological factors involved in prolonged pain reported to influence motor actions [3,7,25,26].

#### Secondary criteria

The second objective was two-fold : to examine the characteristic kinematics of walking and to evaluate the influence of pain perception variables, which could explain the observed critical point values.

#### Gait kinematics

During *approach*, cNSLBP participants exhibited similar behavior to pain-free participants for shoulder rotation, phase shift between the scapular and pelvic angle and trunk stability. These results are in agreement with previous studies performed during straight line walking without speed constraint for shoulder rotation and phase shift between the scapular and pelvic angle [27–29]. In addition, the results showed cNSLBP participants walked slower than participants without pain which is consistent with previous works [29,32]. Furthermore, no effect of the aperture width on walking speed, shoulder rotation, phase shift between the scapular and pelvic angle and trunk stability was found, suggesting that AA and cNSLBP participants did not adapt

their movement during *approach*. This can be explained by the role of the *approach* to collect visual information for precise movement [33] where the adjustments would only be made in the last steps before the door [18,34,35].

At *tcross*, no difference between the groups in walking speed, shoulder rotation and phase shift between the scapular and pelvic angle was found. These results suggested that cNSLBP participants adapted their movement in a similar way to AA participants. The walking speed, shoulder rotation and phase shift between the scapular and pelvic angle were proportional to the ratio between the aperture size and the shoulder width for both groups. Hence, when SA ratio decreased, walking speed decreased and the shoulder angle and phase shift between the scapular and pelvic angle increase, as previously reported [17–19].

#### Pain perception

One of the major current challenges in cNSLBP is to identify the mechanisms involved in prolonged pain associated with changes in motor behavior [3]. In this study, the influence of pain perception variables on the observed critical point values was also explored. Pain perception variables (fear avoidance beliefs, kinesiophobia, anxiety and depression, negative beliefs, quality of life) did not correlate with the critical point value. These results can be explained by the low variability of pain intensity and low scores for all the questionnaires. Thus, the aperture crossing paradigm appears relevant to discriminate cNSLBP participants from participants without pain, but does not enable us to quantify the effect of the level of pain. Further studies are needed, especially on a larger cohort, to observe whether there is a stratification of critical thresholds according to pain level.

Using such a paradigm to measure the effect of cNSLBP seems promising, as it responds to the recommendations of previous work incorporating patient complaints [7] and their ability to perform daily physical activities for basic needs, from self-care to more complex activities requiring a combination of skills. Future work could investigate the effect of cNSLBP on action

strategies in a dynamic environment, such as crossing other pedestrians [36,37] where participants will have to adapt their movements in more challenging situations, but also to bring these protocols to virtual reality which would allow all environmental parameters to be controlled and implemented for clinical purposes.

## **Conclusion**

In conclusion, this study showed cNSLBP participants had a smaller critical point than AA participants while walking through apertures. This strategy may reflect a riskier adaptive strategy to minimize rotations that could induce pain. In addition, these participants have walked slower, which gave them more time to make the movement adaptations necessary to cross the aperture.

## **Acknowledgement**

This study was funded by the University of Rennes 2, France. We would like to thank Spormed and Cindy Richard for their help in the recruitment process, Rebecca Crolan and Lise Leclercq for their help in conducting the experiment as well as all our participants.

## **Conflict of interest statement**

None.

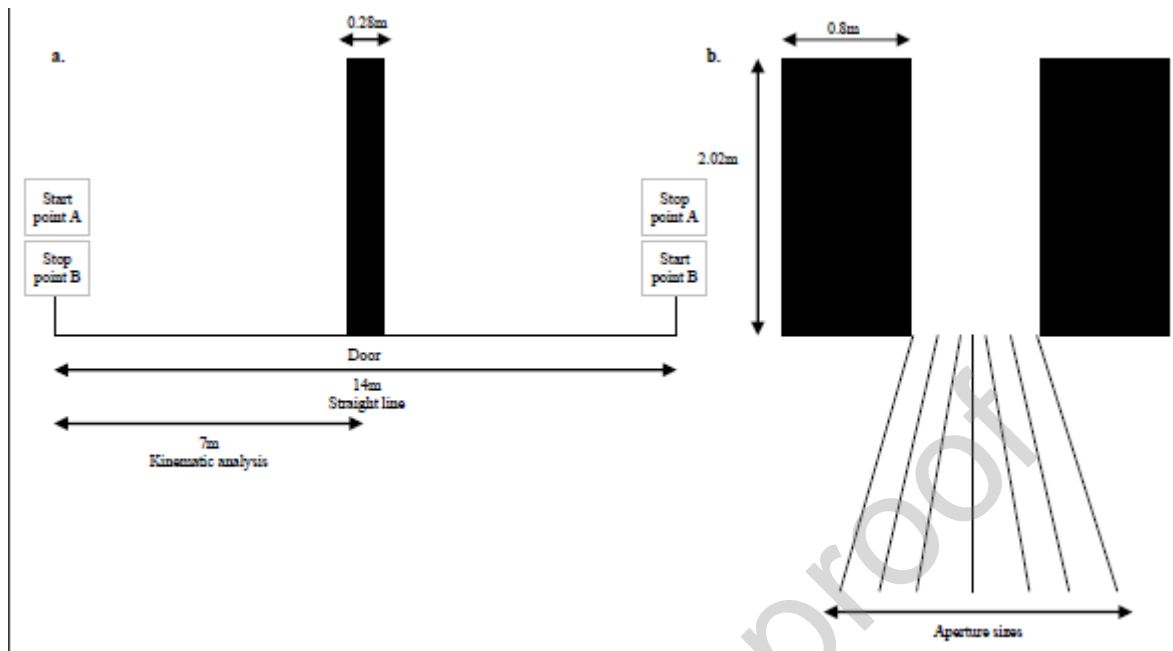
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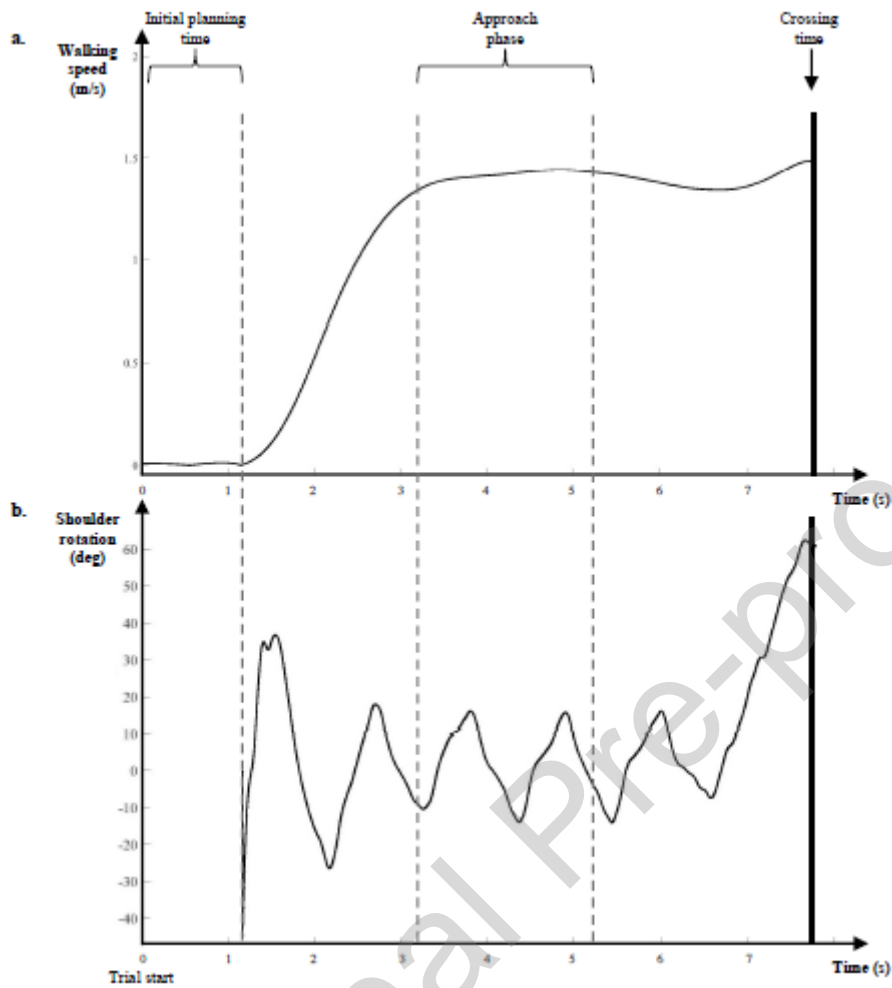
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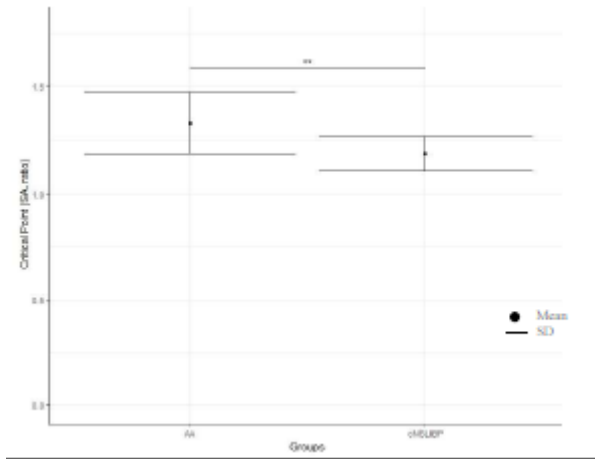




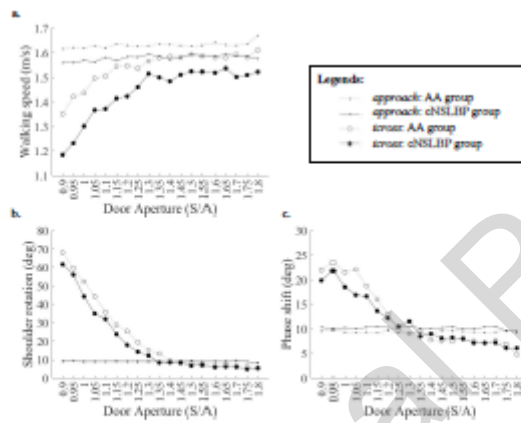
**Fig.1.** Side view (a.) and front view (b.) of the experimental set up. Participants were asked to cross a horizontal opening. We set 19 aperture sizes ranging from 0.9 to 1.8 times their shoulder width (increments of 0.05). The starting point for the even-numbered trials was point A and for the odd-numbered trials point B.



**Fig.2.** Illustration of walking speed (a) and shoulder rotation evolution (b) from the starting time to aperture crossing time ( $t_{cross}$ ). Initial planning time is the time between the moment the participant turns around and sees the opening, and the beginning of the movement. Approach phase begins 2s after the start of the movement and lasts 2s (*approach*). Crossing time refers to the moment when the participant walks through the aperture ( $t_{cross}$ ).



**Fig.3.** Critical point for both groups.



**Fig.4.** Walking speed (a.), shoulder rotation angle (b.) and phase shift between the scapular and pelvic angle (c.) during *approach* and at *tcross* for both groups.

**Table 1.** Participants' characteristics

	cNSLBP	AA	p-value *
<b>Participants (n)</b>	14	15	
<b>Age (y) - mean (sd)</b>	43.7 (14.9)	41.9 (14.1)	0.74
<b>Sex (♂/♀)</b>	5/9	10/5	0.19

<b>Shoulder Width</b> (cm) - mean (sd)	45.9 (3.9)	44.9 (5.1)	0.59
<b>MMSE</b> - median (iqr)	30 (1.8)	29 (0)	0.27
<b>HADS</b> - median (iqr)			
Anxiety	6 (7.8)	4 (4)	0.33
Depression	2 (1.8)	2 (1.5)	0.31
<b>EQ5D</b> - median (iqr)	0.8 (0.1)	1 (0.1)	<0.01 *
<b>RMDQ</b> - mean (sd)	5.31 (3.68)		
<b>FABQ</b> - mean (sd)			
Physical activity	9.79 (6.37)		
Work	8.71 (7.83)		
<b>PCS</b> - mean (sd)	16.86 (10.32)		
<b>TSK</b> - mean (sd)	34.57 (6.57)		
<b>PIPS</b> - mean (sd)			
Avoidance	31.15 (11.46)		
Fusion	28.54 (8.53)		
Total scale	55.43 (19.68)		
<b>VAS</b> - mean (sd)			
T1	1.66 (1.64)		
T2	1.87 (1.20)		
T3	2.10 (1.38)		
T4	2.38 (1.47)		
Total scale	2.00 (1.2)		

\* t test for independent samples ( $p < 0.05$ )

Data reported as mean (std). cNSLBP: Non-Specific Chronic Low Back Pain. MMSE: Mini Mental State Examination (range 0-30). HADS: Hospital Anxiety and Depression Scale with subscales related to anxiety (range 0-21) and to depression (range 0-21). EQ5D: EuroQol 5 Dimension (range 0-1). RMDQ: Roland Morris Disability Questionnaire (range 0-24). FABQ: Fear Avoidance Belief Questionnaire with subscales related to physical activities (range 0-24) and to work (range 0-42). PCS: Pain Catastrophizing Scale (range 0-52). TSK: Tampa Scale Kinesiophobia (range 0-68). PIPS : Psychological Inflexibility in Pain Scale with subscales related to avoidance of pain (range 0-70) and cognitive fusion (range 0-24). VAS: Visual Analog Scale of pain (range 0-10) at time t1, before the experiment, t2 after the first block, t3 after the second block, t4 after the third block.

**Table 2.** Standard deviation of walking speed, shoulder rotation angle and phase shift between the scapular and pelvic angle during *approach* and at *tcross* for both groups.

S/A ratio		0.9	0.95	1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4	1.45	1.5	1.55	1.6	1.65	1.7	1.75	1.8	
<b>Walking speed</b>																					
<i>Approach</i>	AA group	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09	
	cNSLB P group	0.01	0.02	0.01	0.01	0.11	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06
<i>tcross</i>	AA group	0.14	0.12	0.13	0.10	0.09	0.09	0.08	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	
	cNSLB P group	0.11	0.12	0.08	0.07	0.17	0.06	0.06	0.02	0.01	0.02	0.01	0.01	0.00	0.02	0.00	0.02	0.00	0.02	0.07	
<b>Shoulder rotation</b>																					
<i>Approach</i>	AA group	0.88	0.84	0.89	0.90	0.96	0.94	0.95	0.99	0.95	1.00	0.96	0.92	0.93	0.93	0.95	0.92	0.92	0.98	0.90	0.97
	cNSLB P group	1.03	0.08	0.08	0.08	0.88	0.09	0.02	0.08	0.02	0.08	0.07	0.09	0.05	0.09	0.07	0.01	0.03	0.08	0.08	0.08
<i>tcross</i>	AA group	9.25	1.27	1.41	1.18	13.7	1.37	2.11	1.19	1.15	1.14	6.91	5.18	7.19	5.17	4.11	4.16	3.10	2.15	4.13	
	cNSLB P group	1.48	1.59	1.31	1.25	18.2	1.30	0.06	0.08	0.07	0.06	4.42	5.43	4.41	5.40	3.48	3.44	3.45	2.49	2.45	
<b>Phase shift</b>																					
<i>Approach</i>	AA group	0.98	1.03	1.03	1.00	1.15	0.94	1.08	1.02	0.98	1.09	1.04	1.05	1.07	1.05	0.99	1.00	1.08	1.01	1.02	
	cNSLB P group	1.45	1.30	1.27	1.22	1.41	1.41	1.33	1.26	1.25	1.24	1.21	1.21	1.20	1.20	1.23	1.23	1.28	1.22	1.26	1.25
<i>tcross</i>	AA group	4.31	4.41	4.41	3.49	3.82	3.09	3.04	2.09	3.02	2.09	2.06	2.06	1.09	2.09	1.09	1.05	1.06	1.08	1.08	
	cNSLB P group	4.15	4.25	3.24	3.24	4.58	4.21	3.22	3.26	2.25	1.27	2.26	1.27	1.27	2.29	1.29	2.23	1.28	1.28	1.26	

### Conflict of interest statement

None.

## Highlights

- Investigation of cNSLBP movement strategies in an ecological context
- Horizontal aperture crossing paradigm discriminated the influence of cNSLBP
- cNSLBP participants stopped turning their shoulder at a smaller opening
- Pain perception scores were not correlated with the critical point but were low

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