A Comparison of the Spatio-Temporal Parameters during Gait in Subjects with and without Chronic Low Back Pain: A Systematic Review

Poonam, Suprita Desai[1], Nidhi Amonkar[2]

Abstract: ***Background**: In chronic low back pain (CLBP) due to the phenomenon of central sensitization there might be persistent pain and flare-ups. Further due to its lasting periodicity in nature, it also results in significant economic burden. However, the mechanisms for chronicity in low back pain have not been established. **Objectives**: The purpose of this study is to investigate whether there are differences in spatio-temporal parameters in subjects with chronic low back pain compared with the healthy controls subjects during the gait cycle. **Methods**: The methodology used for the systematic review follows the PRISMA guidelines. A literature search was performed in PubMed, EMBASE, Scopus and Medline. Twelve articles comparing spatio-temporal parameters (speed, stride length and step length) in people with CLBP and healthy controls during walking or running were selected. Two persons independently performed the data extraction and quality assessment. **Results**: The results showed that among ten studies which measured the walking speed, only four studies reported significant differences ($p < 0.05$) in the population of CLBP compared to Healthy Control (HC). In respect to stride length, among six studies, only two studies reported a significant difference ($p < 0.05$) between the population of CLBP compared to HC. Eight studies which reported on step length, only three studies found a significant difference ($p < 0.05$) and remaining concluded that there was no significant difference present ($p > 0.05$) between the population of CLBP compared to HC. To summaries, most of the studies found that there were no differences in the spatio-temporal parameters of subjects with and without CLBP during gait. However, the overall results remain inconclusive. Furthermore, due to the limitations to the number of studies on spatio-temporal parameters, future study results are needed to confirm the result. **Conclusion**: The current evidence states that the difference in spatio-temporal parameters during gait of subjects with or without CLBP remains unclear. Furthermore, the differences in acquisition and processing of the data made the comparison difficult to synthesize. Thereby, standardization in future research implication is needed. Future studies should aim at considering the spatio-temporal parameters of gait in order to improve the strength of the evidence.*

Keywords: spatio-temporal parameters, chronic low back pain, gait cycle

1. Introduction

National Institute of Health (NIH) pain consortium task force on research (RTF) standards for Chronic Low Back Pain (2014) defined this condition as 'back pain that has persisted for at least 3 months and resulted in pain on at least half the day in the past 6 months.' Chronic low back pain develops in 5-10% of all low back pain cases (Hoy, 2010). Chronic low back pain results in difficulty in a range of daily activities including sitting, standing or walking especially if there is radiating pain along the lower extremity (O'Sullivan et al, 2018). With chronicity, the phenomenon of central sensitization ((Murray J. McAllister, 2020) can also occur, furthermore, fear avoidance beliefs and pain catastrophizing and depressive thoughts which targets the pain-disability cycle are, linked to increasing pain and disability. (O'Sullivan et al, 2018).

CLBP also leads to significant socioeconomic burden (Dagenais et al., 2008). The mechanisms and causes of CLBP is often unclear, making it challenging to treat. The number of people who need to undergo treatment is also high (Koch and Hansel, 2018). Various mechanisms are discussed for CLBP (Saragiotto et al., 2016). Alteration in muscle activities of abdominal and extensor muscles (Ghamkhar and Kahlaee, 2015) resulting in stiffening of the spine to compensate for unexpected perturbation, alteration in proprioception due to decreased nerve velocity conduction and reflex inhibition (Radebold et al., 2001) and limited range of motion as the compensatory change to stiffened spine (Laird et al., 2014) have all been identified in patients with CLBP, thereby indicating disturbed motor control in patients with chronic LBP.

Movements of daily living require varying degrees of motor control and impairment may hinder with the functioning of motor control (Koch and Hansel, 2018). Walking is an activity that is performed on an everyday basis. The components of gait include movement patterns and the ability to initiate and direct muscle function (Hodges and Tucker, 2011). There are lots of other factors besides the physical factor affecting the gait parameters. For example, the socio-cultural factor which includes the status of economic well-being, size of the population, industrialization, climate and values of the culture that may influence the pacing of life and indirectly parameters of gait (Levine and Norenzayan, 1999). Research has shown that higher the pace of life, higher is walking speed (Levine and Norenzayan, 1999). Population from the countries such as Germany, Switzerland, England, Netherlands and Ireland have a walking speed 0.3 m/s more than the Mexican population and 0.5m/s more than the Brazilian population (Levine and Norenzayan, 1999). Even gender differences play an important role in parameters of gait. The smoother head movements and the higher pelvis acceleration is usually seen in female subjects, possible explanation could better balance control (Mazzà et al., 2009). Studies have shown than males have higher sensitivity index for the changes seen in spatio-temporal parameters and females with broader peripheral view (Abramov et al, 2012). This can be due to the ancient role of males as hunters and and female as child protectors thus giving them a control of larger view (Abramov et al, 2012). There is also psychological factor affecting the parameters of gait, like

Licensed Under Creative Commons Attribution CC BY

mental walking time gradually increases when subject walk with the weight in the back (Riener et al, 2005). The perception also seems to be affected with respect to the position of the target (Decety et al, 1989).

Clinical identification that results from abnormal gait pattern can be measured by gait analysis (Bowker and Messenger, 1988). The description for components of gait is called the kinematic analysis of gait pattern. It is concerned with movements rather than forces acting on the body (kinetic analysis). The spatio (distance) and temporal (time) parameter forms this biomechanical component of kinematic analysis of gait (Bowker and Messenger, 1988).

Evidence has shown that people with Low Back Pain who are given instructions to walk consistently, walk slower at a self-selected walking speed. (Muller et al, 2015). These changes are supported by the pain-spasm-pain and pain adaptation models (Dieën et al, 2003) (Roland, 1986) (Lund, 1991). In the pain-spasm-pain model, in response to pain, muscle activity levels are increased which results in more pain forming a vicious cycle. This cycle of increased contraction, results in over-activity of back muscle and stiffness of spine affecting the walking speed. In the pain adaptation model, there is decrease and increase of agonist and antagonist muscle activity in response to pain (Ghamkhar & Kahlaee, 2015). According to this theory, due to weakness in the back muscles, and the over activity of the abdominals causes change in the walking speed of the subject with CLBP. However, in both the models there is alteration in the muscle causing muscles to perform movement inaccurately. Thereby showing deviations in gait patterns.

A number of studies have investigated biomechanical component of gait in subjects with and without CLBP. One study by Ghamkhar and Kahlaee (2015) reviewed patterns of muscle activation motor during walking in people with and without chronic LBP. They found that there was increased global muscle activity in subject with CLBP and further increase in walking speed challenges the stability of spine. Another study by Koch and Hänsel, 2018 focused on biomechanical component and found that there was a more in-phase coordination, decreased rotational amplitudes and increased Erector spinae muscle activity. However, the study was not specific to spatio-temporal parameters and was more focused on the patterns of muscle activation causing alteration in motor control while walking.

The review will help to focus on three biomechanical components: walking speed, step length and stride length, thereby summarizing differences between groups in order to understand the changes in spatio-temporal parameters in motor control during gait in CLBP that will help in determining whether evaluation and treatment of gait in CLBP will have a significant effect in subjects of CLBP and further will help in strengthening the evidence-based practice.

The aims of this review are to answer the following research question: What are the differences in spatio-temporal parameters between persons with and without CLBP in gait?

2. Methods

This review was undertaken employing the PRISMA guidelines (Moher et al., 2009).

Search strategy:
A literature search was performed in PubMed, EMBASE, Scopus and Medline. The papers were searched from January 2010 to May 2020. "Low back pain" OR " Chronic Low back pain" OR "lumbar pain" And "Healthy Control" AND "Gait" OR "Walking" OR "Running" Not ("spinal stenosis" OR "case study" OR "fractures" OR "disc herniation" OR "amputation" OR "taping" OR "injury" OR "strength" OR "invasive" OR "metabolic") were the keywords in a subject term search. Reference lists of included studies were scanned. The search strategy was restricted to English written articles.

Study selection:
The inclusion criteria for CLBP subjects included:
1) Studies should be either case control or cross- sectional only.
2) Back pain since at least last three months.
3) Subjects above 18 years of age
4) Outcome measure of speed (distance covered per unit time (Kharb et al., 2011)), step length (distance covered between two successive heel contact of the opposite limb (Kharb et al., 2011)) and stride length (distance between point of contact of same foot (Kharb et al., 2011)).
5) Articles published in a peer-reviewed journal in English language.

Exclusion criteria:
1) Low Back Pain caused by pathological involvement, scoliosis, trauma, joint abnormalities of the lower limbs, fractures, arthritis (spine or lower limbs), spinal surgery, pregnancy, fibromyalgia, leg length discrepancy >2 cm, neurological involvement, vascular insufficiency or systemic problems.
2) Studies without the comparison of the HC.
3) Studies with online journal and presentation abstracts, unpublished articles, books, PhD and MSc dissertations.
4) The primary stage of screening included two stages, performed by the reviewer (PT). The first stage included screening of titles and abstracts. The relevant studies selected in the first stage were screened by the articles with full text and were included in the study, if they satisfied the inclusion criteria.

Data extraction from the included studies were performed by the main reviewer (PT) and second reviewer (SD) independently using a customized data collection tool of the Joanna Briggs Data Extraction Form. Data extraction was focused on demographics, procedure, outcome measures, and results from the full text version of the included articles. The Primary outcome measure; walking speed, step length and stride length were represented in terms of p values, effect size (ES), coefficient of regression and the differences in outcome measures of subject with and without CLBP were mentioned in terms of confidence intervals (CI) and p values.

Licensed Under Creative Commons Attribution CC BY

Data extraction Table

Sr. No	Author's Name	Population Mean Age (in years) (SD), Gender (Female, Male), BMI (kg/m2), Race, Weight (kg), Height and Quality Assessment Newcastle- Ottawa Scale (NOS)	Methodology and Ambulatory settings	Primary Outcome Mean (standard deviation) Walking- speed (WS) m/s, Stride length (SL) and step length (ST-L) in meters (m)	Post- hoc analysis of outcome measures: Walking- speed (WS) m/s, Stride length (SL) and step length (ST-L) in meters (m) and Confidence Intervals (CI)	Summary of Results
1.	Bonab et al., 2020	25 – CLBP Mean Age (SD): 43.7 (14.5) Gender: 16F, 9M BMI (Mean (SD)): 26.10 (4.70) Height (cm): 1.65 (0.08) 20 – HC Mean Age (SD): 39.6 (8.3) Gender: 10f, 10M BMI (Mean (SD)): 24.10 (4.50) Height (cm): 1.71 (0.06) 20 – Lumbar Disc Herniation (LDH) Mean Age (SD): 46.0 (12.9) Gender: 13F, 12M BMI (Mean (SD)): 26.5 (3.5) Height (cm): 1.7 (0.09) NOS: 6	The spatiotemporal parameters of gait and the pedobarographic parameters were analysed using the WIN-TRACK gait analysis platform. All participants were asked to walk for10 times (barefoot) in a straight line as much as possible without any assistance on the WIN-TRACK platform. 5 such readings were recorded, and the arithmetic means were computed for the 5 data.	Gait Speed: LDH (GI):188.73 (44.13) CLBP (GII): 586.01 (85.68) Control (GIII): 788.18 (43.09) p-value (GI & GII):0.00 p-value (GII & GIII): 0.00 p-value (GI & GII & GIII): 0.00 Step Length: (Left) LDH (GI): 41.51 (5.30) CMLBP (GII): 50.42 (5.53) Control (GIII): 55.91 (2.50) p-value (GI & GII): 0.00 p-value (GII & GIII): 0.00 p-value (GI & GII & GIII): 0.00 Step Length: (Right) LDH (GI): CMLBP (GII): 50.70 (6.33) Control (GIII): 55.55 (3.43) p-value (GI & GII): 0.00 p-value (GII & GIII): 0.03 p-value (GI & GII & GIII): 0.00	Not mentioned	Spatial parameters of gait compared showed significance when the CMLBP was compared to the healthy controls. ($p<0.05$)
2.	Christe et al., 2017	CLBP-10 Mean Age (SD): 38.7 (7.2) Gender: 4F, 6M Weight (kg) (Mean (SD)): 67.8 (8.9) Height (m): 1.74 (0.07) BMI (Mean (SD)): 22.3 (1.6) HC-11 Mean Age (SD): 36.7 (5.4) Gender: 5F, 6M Weight (kg) (Mean (SD)): 69.5 (9.8) Height (m): 1.74	A camera-based motion capture system recording using a reflective marker was attached to the participants at 120 Hz (VICON, Oxford Metrics, UK). 19 markers were placed on the pelvis and spine and the 20th marker was attached to the lateral side of the right heel. Participants walked 10-meter long walkway at normal self-selected speed. Three trials were taken.	WS: CLBP: (median of 1.14 m/s [interquartile range (IQR):1.00–1.24]) HC: (median of 1.21 m/s [IQR: 1.14–1.36]) groups) P value: 0.051	Not mentioned	Walking speed was not significantly different between the CLBP and control $p < 0.5$.

Licensed Under Creative Commons Attribution CC BY

		(0.05) BMI (Mean (SD)): 22.9 (3.8) NOS: 7				
3.	Demirel et al., 2020	66 (33 moderate, 33 severe) - (CLBP) Mean Age (SD): 44.8 (11.67) Gender: 50F, 11M BMI (Mean (SD)): 27.33 (5.52) Height (cm): 163.89 (8.25) 32 -HC Mean Age (SD): 40.81 (10.95) Gender: 22F, 10M BMI (Mean (SD)): 25.85 (4.43) Height (cm): 164.25 (14.95) Overall Age: 25-65 years NOS: 7	Optogait treadmill-based photocell system was used. The participants were asked to walk on the treadmill at a self-chosen speed of comfort. When the participant started walking, their gait characteristics were recorded for 1-min of walking on the treadmill.	Self-selected gait speed: Moderate: 3.92 (0.75) Severe: 4.30 (0.87) HC: 4.51 (1.08) p-value: 0.031 Step length: Moderate: 57 (7.84) Severe: 61.17 (9.5) HC: 65.53 (10.74) p-value: 0.02 Stride length: Moderate: 114.45 (16) Severe: 121.93 (18.69) HC: 126.2 (21) p-value: 0.038	Self-selected gait speed: Moderate-severe: Mean difference: -0.38 CI: -0.91 to 0.15 p-value: 0.20 Moderate-HC: Mean difference: -0.59 CI: -1.12 to -0.05 p-value: 0.02 Severe-HC Mean difference: -0.2 CI: -0.75 to 0.33 p-value: 0.269 Step length: Moderate-severe: Mean difference: -4.17 CI: -9.69 to 1.34 p-value: 0.17 Moderate-HC: Mean difference: -6.52 CI: -12.04 to -1 p-value: 0.01 Severe-HC Mean difference: -2.35 CI: -7.95 to 3.24 p-value: 0.57 Stride length: Moderate-severe: Mean difference: -7.47 CI: -18.39 to 3.44 p-value: 0.233 Moderate-HC: Mean difference: -11.75 CI: -22.67 to -0.82 p-value: 0.03 Severe-HC Mean difference: -4.27 CI: -15.36 to 6.81 p-value: 0.63	Between CLBP and healthy control: The self-selected speed, step length and stride length were higher than both groups of patients with CLBP (p = 0.031, p = 0.020 an p = 0.038). Between Moderate and healthy control: Healthy controls had higher values in step length, stride length, and self-selected speed parameters compared to moderate CLBP patients (p < 0.05) Between Moderate CLBP and severe CLBP groups: Self-selected speed was lower in the moderate CLBP group than severe CLBP group, this did not reach statistical significance (p > 0.05)
4.	Ebrahimi et al., 2017	CLBP- 10 Mean Age (SD): 29.4 (6.38) Gender: Not mentioned Weight (Mean (SD)): 68.07 (12.92) Height (cm): 167.40 (8.19) HC- 10 Mean Age (SD): 29.60 (5.64) Gender: Not mentioned Weight (Mean (SD)): 62.38	Kinematic data were collected using an eight-camera motion analysis system (Proreflex, Qualisys Track Manager® Ltd., Gothenburg, Sweden) at a sampling rate of 100 Hz.	WS: CLBP: 0.90 (0.13) HC: 1.26 (0.16) P value: <0.001	Not mentioned	The mean difference in walking speed in CLBP was significantly lower than the HC p < 0.001.

Licensed Under Creative Commons Attribution CC BY

		(13.12) Height (cm): 167.40 (7.36) NOS: 9				
5.	Gombatto et al., 2015	CLBP- 18 Mean Age (SD): 28.1 (13.1) Gender: 11F, 7M Weight (kg) (Mean (SD)): 71.2 (15.3) Height (cm): 169.9 (11.5) BMI (Mean (SD)): 24.4 (2.9) HC-18 Mean Age (SD): 27.6 (12.4) Gender: 10F, 8M Weight (kg) (Mean (SD)): 72.0 (14.5) Height (cm): 167.8 (12.5) BMI (Mean (SD)): 25.5 (3.6) NOS: 7	A 9-camera, three-dimensional movement analysis system (Vicon, Inc.) was used. Reflective markers were placed 4 cm lateral to L1 and L4, centrally on L3 and L5, on bilateral PSIS, ASIS, and iliac crests. The subjects were asked to walk on 10 m walkway. Their speed was synchronized with beats of a metronome at 96 bpm, to reach a target pace of 1.2 m/s. Three trials were done.	WS: CLBP: 1.0 (0.2) HC: 1.0 (0.1) P Value: 0.61 SL: (Left) CLBP:0.6(0.1) HC:0.6 (0.1) P value; 0.42 SL: (Right) CLBP:0.6 (0.1) HC:0.6 (0.1) P value; 0.34 ST-L (Left) CLBP; 1.2 (0.1) HC; 1.2 (0.1) P value: 0.63 ST-L (Right) CLBP: 1.2 (0.1) HC: 1.2 (0.2) P value: 0.40	Not mentioned	There were no significant differences in characteristics in between groups p >0.5. Less than 25% reported limitation to pain while walking during testing.
6.	Hanada et al., 2011	9 - (CLBP) Mean Age (SD): 61.4 (9.8) BMI (Mean (SD)):26.0 (6.6) Height (cm): 166.7 (6.7) 9 - HC Mean Age (SD): 64.9 (8.8) Gender: Not mentioned BMI (Mean (SD)): 25.6 (2.4) Height (cm): 170.1 (9.5) NOS: 5	There was a 20mm center-to-center distance between the Ag-AgCl pair of surface electrodes as stated in the standard procedure of application of EMG. They were placed at standard locations on the skin above the left and right sides of the LRA, LES, IO and LM muscles. Participants were asked to perform 4 walking trials over a GAITRite mat (4m in length) at a self-selected pace. Waling velocity was measured and was remeasured if it deferred by more than 5%.	Gait Speed: Control: 136.7 (21.4) CLBP: 135 (11.7) p-value: 0.846 Step length: Control: 74.34 (8.96) CLBP: 71.72 (7.66) p-value: 0.515	Not mentioned	None of the spatiotemporal parameters showed any significance differences between control and CLBP groups for baseline measures with p >0.5. Although the greatest difference between the groups was that they LBP group walked with a 1.4cm (16%) wider base of support.
7.	Hicks et al 2017	54 - CBLP– Mean age (SD): 69.3 (6.7) Gender: 37F and 17M BMI (Mean (SD)): 29.1 (5.6) Race: White- 51 54 – HC Mean age (SD): 71.1 (6.8) Gender: 37F and 17M BMI (Mean (SD)): 20 (4.8) Race: White- 49	Participants walked on the GaitMat II system, for 4metres on the walkway 3 times at their self-selected comfortable speed and again 3 times at the fastest possible speed that they can walk. They were given 2 practice trials before they started the actual assessment.	SELF-SELECTED PACE Stride length: CLBP: 1.19 No CLBP: 1.31 p-value: - 0.001 ES: 0.7 Step width: CLBP: 0.48 No CLBP: 0.32 p-value: 0.35 ES: 0.44 FAST-PACED GAIT Stride length CLBP: 1.34	SELF-SELECTED PACE Stride length: Difference (95%-CI): -0.122 (-0.192 TO -0.052) Step width: Difference (95% CI): 0.16 (0.001 to 0.032) FAST-PACED GAIT Stride length Difference (95% CI): -0.069 (-0.17 to 0.032)	A significant overall difference between groups for spatiotemporal parameters of gait (p=.002) at a self-selected speed and fast gait (p=.036) was found when compared to HC

Licensed Under Creative Commons Attribution CC BY

		(age and sex matched) NOS: 8		No CLBP: 1.41 p-value: 0.178 ES: 0.29 Step length: CLBP: 0.055 No CLBP: 0.035 p-value: 0.016 ES: 0.5	Step width: Difference (95% CI): 0.019 (0.004 to 0.035)	
8.	Hoorn et al., 2012	13- CLBP Mean Age (SD): 35.3 (12.4) Gender: 8F, 5M Weight (kg) (Mean (SD)): 72.3 (13.4) Height (m): 1.75 (0.13) 12- HC Mean Age (SD): 32.3 (13.1) Gender: 8F, 4M Weight (kg) (Mean (SD)): 75.3 (11.2) Height (m): 1.72 (0.10) NOS: 7	Participants were instructed to walk on a trade mill at the speed from 0.5 to 1.75 m/s with an increasement of 0.11 m/s for 3 mins for each of the 12 speeds between the above given range. Neoprene bands, with a 2×3 camera array (OPTOTRAK Certus, Northern Digital Inc., Waterloo, Ontario)), was attached to the participant's body, at the thorax (T6), pelvis (PSIS), and on the heels. The two cameras arrays were positioned ~4 m behind, and ~2 m to each side of the participant.	Stride time (s): Coefficient of regression: −0.02 P value: 0.51 Stride length (m): Coefficient of regression: 0.01 P value: 0.73	Not mentioned	There was no significant difference present with respect to step length in between groups p >0.05. However, the step length increased with increasing speed respectively for both groups. As this is a regression model, a group X time interaction has been made note of.
9.	MacRae et al., 2018	16 – CLBP Mean Age (SD): 36.8 (10.1) Gender: 8F, 8M Weight (kg) (Mean (SD)): 73.4 (10.6) Height (cm): 173.4 (8.9) 16 – HC Mean Age (SD): 37.3 (11.1) Gender: 8F, 8M Weight (kg) (Mean (SD)): 76.3 (13.6) Height (cm): 173.4 (9.3) NOS:8	17 reflective markers were positioned on each participant. The modified Helen Hayes marker set was implemented with an additional marker on the B/L crests and posterior calcanei. Then, the subject was asked to walk barefoot at a self-selected comfortable pace in a line which crossed 3 force plates from one end of the lab to another. They continued doing so until clear force plates strikes were observed by the researchers for each of the foot respectively.	Walking speed: Asymptomatic: 1.32 (0.13) CLBP: 1.25 (0.2) p-value: 0.26 Stride Length: Asymptomatic: 1.38 (0.12) CLBP: 1.33 (0.13) p-value: 0.33	Not mentioned	Results indicate that one of the parameters of spatiotemporal gait were found to be not significant with p > 0.1 in comparison with healthy controls.
10.	Müller et al., 2015	11- (CLBP) Mean Age (SD): 38.2 (13.9) Gender: 6F, 5M Weight (kg) (Mean (SD)): 68.5 (12.5) Height (cm): 171.2 (5.9) BMI (Mean (SD)): 23.2 (3.1) 11 –(HC) Mean Age (SD): 38.5 (12.1)	The subjects were instructed to first walk and then run at their own pace on a 17 m walkway. The markers were placed on the tip of the toe, lateral malleolus, epicondylus lateralis and trochanter major on bilateral lower limbs, acromion, L5 and C7 spinous process. All (5) trials were recorded with eight cameras (240 Hz) by a 3D infrared system	Walking: WS: Level- HC: 1.97 (0.13) CLBP: 1.84 (0.13) P value: 0.000 Uneven- HC: 1.95 (0.12) CLBP: 1.83 (0.14) P value: 0.000 Running: WS: Level-	Not mentioned	There was a reduction of 6.5% of walking speed on level ground (p<0.01) compared to HC and reduction of 6% on uneven ground (p<0.01). During running, there was no significant difference noted. Step length did not change in CLBP patients when compared to HC, during walking or during running.

Licensed Under Creative Commons Attribution CC BY
Paper ID: SR21731123052 DOI: 10.21275/SR21731123052

		Gender: 6F, 5M Weight (kg) (Mean (SD)): 67.6 (11.6) Height (cm): 169.6 (7.7) BMI (Mean (SD): 23.4 (3.0) Individual Age, Height Weight and BMI are also mentioned in Table 1 in the original paper. NOS: 5	(MCU 1000, Qualisys, Gothenburg, Sweden) and synchronized by using the trigger of the Kistler soft- and hardware. Ambulation was undertaken on the ground surface. The outcome recorded were further divided into level and uneven ground surfaces.	HC: 2.76 (0.23) CLBP: 2.66 (0.27) P value: 0.066 Uneven- HC: 2.67 (0.20) CLBP: 2.59 (0.23) P value: 0.101 Walking: (ST-L) Level- HC: 0.96 (0.04) CLBP: 0.95 (0.03) P value: 0.073 Uneven- HC: 0.99 (0.04) CLBP: 0.97 (0.06) P value: 0.070 Running: (ST-L) Level- HC: 0.99 (0.04) CLBP: 1.00 (0.04) P value: 0.465 Uneven- HC: 1.03 (0.04) CLBP: 1.01 (0.03) P value: 0.069		
11.	Newell et al., 2010	12- CLBP Gender: 7F, 5M 12- HC Gender: 8F, 4M Overall Age group: 18 – 50 years NOS: 6	Subjects were instructed to walk on a trade mill for 8 mins. Three trial were taken. The examiner adjusted the walking speed when verbally the participant said that was their comfortable speed, then the examiner increased the speed and the participants had to reduce this speed to their preferred speed (PS) and next the examiner decreased the speed and the participant had to increase the speed to adjust to their PS. Final PS was the average of the 3 trials taken. Data analysis was done using signal analysis software (BIOPAC AcqKnowledgeTM)	WS: CLBP: 0.91(0.15) HC:0.97 (0.27) P Value: 0.51 SL: CLBP:0.87 (0.05) HC:0.90 (0.08) P value; 0.32 ST-L (Left) CLBP; 0.54(0.06) HC; 0.56 (0.12) P value: 0.51 ST-L (Right) CLBP: 0.49 (0.11) HC: 0.49 (0.13) P value: 1.00	Not mentioned	There was a no significant difference present in walking speed, step and stride length with p> 0.1 in CLBP as compared to HC.
12.	Zahraee et al., 2014	20 -nonspecific Chronic low back pain (CLBP) Mean Age (SD): 41.56 (9.57) Gender: 20F Weight (kg) (Mean (SD)): 61.68 (8.88) Height (cm): 158.81 (5.56) 20 healthy subjects Mean Age (SD):	5 successful trials were selected out of the trials performed by the participants. Each participant was asked to walk along the gait lab path with a comfortable speed. The force plate used to record the forces on the leg during walking was the Kistler force plate.	Gait speed: CLBP: 9.2 (1.3) Normal: 9.53 (0.99) p-value: 0.245 Stride Length: CLBP: 1.13 (0.093) Normal: 11.62 (0.77) p-value: 0.17	Not mentioned	There was no significant difference in the mean values of spatiotemporal gait parameters between health participants and patients with NCLBP (*P*> 0.05).

Licensed Under Creative Commons Attribution CC BY

		40.18 (8.55) Gender: 20F Weight (kg) (Mean (SD)): 60.25 (6.38) Height (cm): 158.18 (5.74) NOS: 8				

Data Synthesis

A table was drafted for synthesis of the results. Initial coding for data was made by one reviewer (P.T). Later this data was cross- examined by second reviewer (S.D). Quality assessment was done independently by both the reviewers (P.T and S.D). However, due to the high level of heterogeneity, in terms of variability of the participants (clinical heterogeneity) and variability in risk of bias, study design and outcome measurement tools (methodological heterogeneity), no attempt was made for statistical pooling of results (training.cochrane.org, n.d.).

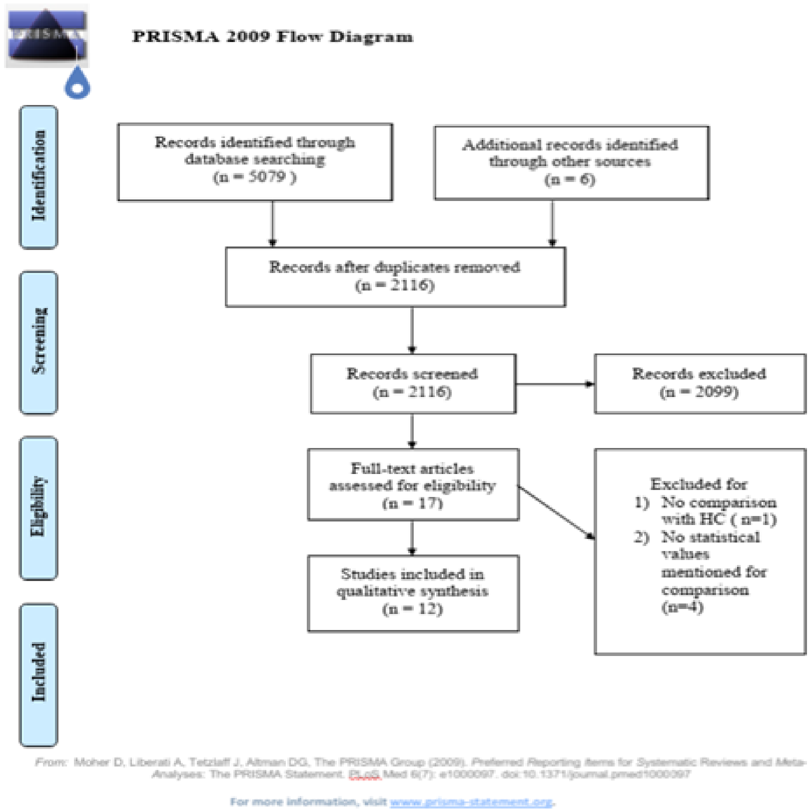
Risk of Bias Rating

The quality assessment was done using the modified version of the Newcastle-Ottawa-Scale (NOS) (Wells et al., 2000). It is appropriate, easy to use as it allows the users to modify the components within the scale and is the most used tool used for observational studies (Ma et al., 2020) (Deeks et al., 2003). Moreover, Downs and Black and NICE checklist are nowadays not used and recommended for the studies included within this review (Ma et al., 2020). The modified NOS has four components comprising ten questions: selection, comparability, exposure and data acquisition (from the Quality Assessment Tool for Quantitative Studies of the Effective Public Health Practice Project (Thomas, 2003)). The scoring was done as positive ("yes"), negative ("no") or unclear ("k"). Each positive criterion that was given the score of one or two points. Two points were awarded to two criteria. There was no differentiation between negative or unclear answers. A maximum of 12 points can be scored. (Koch and Hänsel, 2018). Quality assessment was done by two reviewers independently.

3. Results

Literature Search

A total of 5085 articles were identified across four data bases. 2116 titles and abstracts were screened according to inclusion and exclusion criteria. Seventeen full text articles were identified after screening for inclusion and exclusion criteria. Reference lists of included articles were also hand searched. Five articles were removed. One study (Elbaz et al., 2009) measured the gait parameter, however there was no comparison with a healthy control group. The remaining four studies (Lamoth et al., 2002; Lamoth et al., 2006a, b; Vogt et al., 2003) presented data given ingraphical format and did not provide details of the raw data and or statistical significance between the groups. Twelve articles were included which compared temporal-spatial parameters in chronic back pain patients with healthy control during gait. Endnote software was used for record of researches from electronic databases. All Duplicates were removed.



Licensed Under Creative Commons Attribution CC BY

Classification of studies

In the included twelve studies, 489 subjects were investigated (CLBP: 264, Healthy Controls: 225). Sample sizes varied from 9 (Hanada et al., 2011) to 54 (Hicks et al 2017). In ten studies, gender was mentioned as a confounding factor (Hicks et al., 2017; Demirel et al., 2020; Bonabet al., 2020; MacRae et al., 2018; Zahraee et al., 2014; Müller et al., 2015; Newell et al., 2010; Hoorn et al., 2012; Gombatto et al., 2015; Christe et al., 2017). Age ranged from 18 as the minimum include age of the participant (Newell et al., 2010) to 69 years as the maximum included age of the participant (Hicks et al 2017). BMI details were included in seven studies (Hicks et al., 2017; Demirel et al., 2020; Bonab et al., 2020; Hanada et al., 2011; Müller et al., 2015; Gombatto et al., 2015; Christe et al., 2017) ranging from a mean of 23 (Müller et al., 2015) to 29.1 (Hicks et al 2017). Weight was included in seven studies (MacRae et al., 2018; Zahraee et al., 2014; Müller et al., 2015; Hoorn et al., 2012; Gombatto et al., 2015; Christe et al., 2017; Ebrahimi et al., 2017) ranging from a mean of 61 kg (MacRae et al., 2018) to 73 kg (Zahraee et al., 2014). Height was mentioned in ten studies (Demirel et al., 2020; Bonab et al., 2020; MacRae et al., 2018; Zahraee et al., 2014; Hanada et al., 2011; Müller et al., 2015; Hoorn et al., 2012; Gombatto et al., 2015; Christe et al., 2017; Ebrahimi et al., 2017) ranging from a mean of 158 cm (MacRae et al., 2018) to 175 cm (Hoorn et al., 2012). and ethnicity was addressed in only one study (Hicks et al., 2017).

Regarding the quality of assessment using NOS scale, a high-quality score was defined by a score of eight and above (Koch and Hänsel, 2018). As shown in the data extraction table, nine points was the highest achieved score (Ebrahimi et al., 2017). Three studies were of high quality with a score of eight (MacRae et al 2017. Zahraee et al., 2014; Hicks et al., 2017). Another six articles (Demirel et al., 2020; Bonab et al., 2020; Newell et al., 2010; Hoorn et al., 2012; Gombatto et al., 2015; Christe et al., 2017) scored seven or six points. These studies were of moderate quality. Two studies scored five and were of? quality (Hanada et al., 2011; Müller et al., 2015)

Two of the quality assessment criteria were not mentioned in any of the included studies. Question eight which addresses the awareness of the outcome assessor about the exposure status of the participants and question ten that addresses the non- response rate were not reported in any of the studies.

Synthesis of results

Only two studies reported the results of post hoc analysis between the outcome measures of walking speed, step length and stride length (Demirel et al., 2020) and differences in stride length (Hicks et al 2017) in subject with and without CLBP in the spatiotemporal parameters with a significant difference of $p < 0.05$. The study by Hicks et al (2017), focussed on an elderly population above 65 years of age since gait is also a predictor for the limitation of mobility and falls (Studenski et al., 2011; Abellan van Kan G et al., 2009; Cesari et al., 2005). Groups were matched on age and gender with no difference between groups ($p <0.05$) but those with CLBP had a higher BMI (p=.044). Demirel et al., (2020) study subdivided the group of CLBP into moderate CLBP and severe CLBP and then correlated this with HC subjects. They found that there was significance difference between moderate CLBP and HC ($p < 0.05$). However, when the severe CLBP was compared to HC it did not find any statistical difference ($p > 0.05$). In terms of cofounding factors there was no significant difference in age, BMI, female gender and height between the groups ($p > 0.05$).

Four out of ten studies (Demirel et al., 2020; Bonab et al., 2020; Müller et al., 2015; Ebrahimi et al., 2017) reported a slower walking speed in the CLBP group compared to healthy controls ($p < 0.05$). The study done by Demirel et al., 2020 found the post hoc analysis (one-way ANOVA) of speed in between group, where they found that Moderate CLBP-HC group had a mean difference [CI: -1.12 to -0.05 (p-value: 0.02)] and Severe CLBP-HC group had a mean difference [CI: -0.75 to 0.33 (p-value: 0.269)]. There was no statistical difference in age, gender, height and BMI between the groups in Bonab et al., (2020) and Ebrahimi et al., 2017 where weight was mentioned instead of BMI. In contrast, six studies found no significant differences in walking velocity between groups with $p > 0.05$ ((Zahraee et al., 2014; Hanada et al., 2011; Gombatto et al., 2015; Christe et al., 2017; MacRae et al., 2018; Newell et al., 2010). Two of the studies which found no difference were of high quality (Zahraee et al., 2014; MacRae et al., 2018). There was no significant difference for the cofounding factors of age, gender, weight and height between the groups with $p >0.05$ in study by MacRae et al., (2018) and Newell et al., (2010). In addition to these factors, Zahraee et al., (2014) reported gender specific results in female subjects and Hanada et al., 2011; Gombatto et al., 2015; Christe et al., 2017 reported results based on BMI of subjects. However, there was no significant difference between groups in both the factors ($p > 0.05$).

Six studies compared stride length (Hicks et al., 2017; Demirel et al., 2020; MacRae et al., 2018; Zahraee et al., 2014; Newell et al., 2010; Gombatto et al., 2015). Two studies reported a significant difference in stride length between the groups with $p < 0.05$ (Hicks et al., 2017; Demirel et al., 2020). Hicks et al., 2017, a high-quality study performed post hoc analysis (MANOVA) [(95 %-CI): (-22.67 to -0.82)], reported greater stride length difference than the study reported by Demirel et al., 2020 (one-way ANOVA) [(95%-CI): -0.122 (-0.192 TO -0.052)]. Other studies did not find any significance difference in stride length between the groups ($p > 0.05$).

Step length was evaluated in seven studies (Demirel et al., 2020; Bonab et al., 2020; Hanada et al., 2011; Müller et al., 2015; Newell et al., 2010; Hoorn et al., 2012; Gombatto et al., 2015). There was a significant difference in step length found in two studies with $p < 0.05$ (Demirel et al., 2020; Bonab et al., 2020) The study by Demirel et al., 2020 showed post hoc analysis (one-way ANOVA) in between Moderate CLBP-HC group [CI: -12.04 to -1 (p = 0.01)] and Severe CLBP-HC group [CI: -7.95 to 3.24 (p: 0.57). The remaining five studies did not find any significant difference in stride length between the groups (Hanada et al., 2011; Müller et al., 2015; Hoorn et al., 2012; Newell et al., 2010; Gombatto et al., 2015).

Licensed Under Creative Commons Attribution CC BY
Paper ID: SR21731123052 DOI: 10.21275/SR21731123052

4. Discussion

This systematic review addresses an overview of differences in spatio-temporal parameters of gait between persons with and without CLBP. This review identified twelve studies which assessed spatio-temporal parameters of gait in CLBP subjects. According to GRADE guidelines, the results of this systematic review are deemed of low-quality as the study designs included within this review were all observational studies, which cannot be rated higher as they are not designed to determine effectiveness(Balshem et al., 2011). Most of the included studies in this review were of moderate quality, only one high-quality study could be retrieved. This study identified the difference in spatio-temporal parameters in terms of step length, stride length and speed of walking in subjects with and without CLBP and found the evidence regarding the differences to be inconclusive. The results for this review are discussed below.

Ten studies (Bonab et al., 2020; Demirel et al., 2020; Ebrahami et al., 2017; Müller et al., 2015; Zahraee et al., 2017; Hanada et al., 2011; Gombatto et al., 2015; Christe et al., 2017; MacRae et al., 2018; Newell et al., 2010) assessed the differences in walking speed between CLBP subjects and HC. Four studies (Bonab et al., 2020; Demirel et al., 2020; Ebrahami et al., 2017; Müller et al., 2015) reported a more significant decrease in walking speed in the CLBP group when compared to the HCgroup ($p<0.05$), while six studies (Zahraee et al., 2017; Hanada et al., 2011; Gombatto et al., 2015; Christe et al., 2017; MacRae et al., 2018; Newell et al., 2010) did not find any difference in walking speeds between the two groups ($p>0.05$).

Six studies (Demirel et al., 2020; Hicks et al., 2017; MacRae et al., 2018; Zahraee et al., 2014; Newell et al., 2010; Gombatto et al., 2015) evaluated the differences in stride length between CLBP subjects and HC group. Two studies (Demirel et al, 2020; Hicks et al., 2017) indicated a statistically difference between the groups, with the stride length in the CLBP group reported to be lesser when compared to the HCgroup ($p<0.05$). The remaining studies did not find any statistically significant difference in stride length between the two groups ($p>0.05$)(MacRae et al., 2018; Zahraee et al., 2014; Newell et al., 2010; Gombatto et al., 2015).

Seven studies observed for differences in step length between CLBP subjects and healthy controls (Demirel et al., 2020; Bonab et al., 2020; Hanada et al., 2011; Müller et al., 2015; Newell et al., 2010; Hoorn et al., 2012; Gombatto et al., 2015). Among these studies, only two (Demirel et al., 2020; Bonab et al., 2020) reported a statistically significant difference between both the groups, with step length being lower in the CLBP group in comparison to the healthy control group ($p<0.05$). Five studies found no statistically significant differences in both the groups ($p>0.05$) (Hanada et al., 2011; Müller et al., 2015; Newell et al., 2010; Hoorn et al., 2012; Gombatto et al., 2015).

Three studies (Demirel et al., 2020; Newell et al., 2010; Hoorn et al., 2012) performed their walking trials on a treadmill, while the remaining eight (Bonab et al., 2020; Ebrahami et al., 2017; Müller et al., 2015; Zahraee et al., 2017; Hanada et al., 2011; Gombatto et al., 2015; Christe et al., 2017; MacRae et al., 2018; Hicks et al., 2017) used normal ground walking. One study which used a treadmill (Demirel et al., 2020) found a statistically significant difference in walking velocity, with a higher walking velocity in the HCgroup compared to the CBLP group ($p<0.05$). However, the other two studies (Newell et al., 2010; Hoorn et al., 2012) did not find any significant difference in velocity of walking. This can be due to a phenomenon known as 'sensory movement' (Graci et al., 2009; Pontzer et al, 2009). It involves numerous bits of information coming from the limbs via afferent neurons to compensate for irregularities on the ground (Graci et al., 2009; Pontzer et al, 2009). Any sensory loss or reduction affects proprioception, which affects kinesthetic sense (Graci et al., 2009; Pontzer et al, 2009); this potentially also explains why the elderly subjects of CLBP showed a significant reduction in spatio-temporal parameters compared to the HC (Hicks et al., 2017).

Evidence regarding the walking speed remains conflicting. All twelve studies instructed the subjects to walk at their self-paced speed. However, two studies also assessed the gait parameters of the subjects while running along with normal self-paced walking (Hicks et al., 2017; Newell et al., 2010). Only Hicks et al. (2017), found a difference in gait speed ($p=.036$) when compared to the HC group. Overall, majority of the studies showed that speed of walking have no effect on spatio-temporal parameters. Unlike the results obtained in this systematic review, a systematic review previously conducted by Ghamkhar and Kahlaee (2015) reported that there was decrease in walking speed when subjects with CLBP walked on treadmill when compared to HC. Further the increased velocity of walking seems to threaten the spinal stability which is confronted by increased level of muscle activity of the spine.

Demirel et al. (2020) further classified the CLBP subjects into moderate and severe CLBP. The authors reported that between the moderate-CLBP and HC groups; the HC group had higher values in step length, stride length, and self-selected speed parameters compared to moderate CLBP patients ($p<0.05$) and between Moderate CLBP and severe CLBP groups; self-selected speed was lower in the moderate CLBP group than severe CLBP group, however, this did not reach statistical significance ($p>0.05$)

In the study by Bonab et al. (2020), subjects were divided into those who had lumbar disc herniation (n=25), CLBP (n=25) and 20 healthy individuals for the control group. They found significant difference between the groups in terms of temporal as well as spatial gait parameters ($p<0.05$).

The potential mechanism for no change in spatio-temporal parameters of gait is not clear. However, Lee et al (2014) hypothesized that gait training may lead to increased isometric contraction of the back muscles like Multifidus and Erector spinae. Moreover, these muscles fibers have a large proportion of slow twitch type I fibers that are more fatigue-resistant than fast twitch type II fibers (Ellingson et al., 2014). Hence the isometric contractions may have a strengthening effect on the spine. This effect of

Licensed Under Creative Commons Attribution CC BY

strengthening will indirectly compensate for the pain in the back and hence the subjects will have no significant change in the gait. As concluded by majority of the studies within this review.

Müller et al. (2015) noted differences in walking speed on even and uneven surfaces with walking. These differences can be explained by the fact that when people with low back pain (irrespective of their pain distribution) are given the choice to walk at their preferred speed, they tend to walk slower than pain-free individuals with correspondingly less vertical ground reaction force (Lee et al., 2007). However, when the walking surfaces are changed to uneven, the subjects need to be more aware of where to place the next step in order to adjust to the different angles, textures, springiness and supportiveness, thus making it a mindful experience (Graci et al., 2009; Pontzer et al, 2009).

There were certain limitations in this systematic review, including characteristics of the sample and methods used. The first limitation was that only twelve published studies in regards to spatiotemporal gait parameters in CLBP satisfied the criteria of inclusion and exclusion, in spite of wide search strategy. In addition to that, since it was an observational study, the quality and the strength of evidence was poor. Observational studies often result in selection bias and confounding within the study population (Lu, C.Y., 2009). There was inconsistency in the criteria for determining CLBP. In the study by Hicks et al (2017), the CLBP group were classified as having intensity of pain more than or equal to 3/10, occurring more than 4 days per week for minimum of 3 months of duration whereas in the study by Demireletal.(2020), the patient’s characteristics of CLBP were divided into moderate CLBP and severe CLBP based on the ODI scale. Hence resulting in selection bias.

There was also a difference seen in of control group. In the study by MacRae et al. (2018), wherein the HC were the asymptomatic adults recruited from acquaintances and colleagues of the investigators, hence the blinding could have been hampered. In another study by Hoorn et al. (2012), the researchers recruited healthy controls from the community who presented with no current history of LBP or no history of LBP occurred within past 3 years. Thus leading to procedure bias. Furthermore, most of the studies included within this review did not have proper sample size. Only one study by Demirel et al. (2020) calculated the sample sizeusing GPower 3.0 analysis program.

In regards to the rating scale, a study done by Hartling et al. (2013), showed that reliability score of NOS was fair (κ = 0.29, 95% CI = 0.10, 0.47). Also, the studies addressed within this review did not report two criteria; a) whether the outcome assessor were aware of the exposure status of the participants? b) Non response rate. Hence, the standards of describing the approach for methodology needed to be modified. The study quality was based on conservative estimates, which means that there were no points given when criteria was not reported or fulfilled. Hence the insufficient estimation for methodological quality was due to reporting rather than a poor design for study or approach of methodology which forms a major drawback. Hence the quality for quality rating of studies was affected.

Other limitations include the English language restriction and in spite of the use of broad search strategy, the search might have yielded adequate results for the study.

To conclude, the overall evidence to determine the presence of any differences in spatio-temporal parameters between individuals with and without CLBP during gait remains unclear. The appropriate selection, the assessment and comparability of the confounders between the groups is recommended with further use of statistical techniques in the date analysis. Thus minimizing the selection bias and eventually the confounding associated with it (Lu, C.Y., 2009). Further research should aim to clarify differences in characteristics of the subjects in both groups. Future research should aim at conducting studies using meta-analysis, thus combining biomechanical, neuromuscular and kinematic data so that the relation between these could be better understood for motor control. Furthermore, if the change in altered spatio-temporal parameters is understood, itmay provide better knowledge regarding the assessment and potential management of these patients.

5. Conclusion

Based on the evidence presented in the study, it remains inconclusive whether there are significant differences seen in the spatio-temporal parameters in subjects with and without CLBP. However, most of the studies addressed in this review showed that there were no differences seen in spatio-temporal parameters in subjects with and without CLBP. Also since the study was observational, the quality of the study remained poor. Future studies should aim at the interventional based research, in order to address gait and pain performances considering the important confounding factors like age, gender, sex, height and weight. This will also help in bringing a suitable conclusion with standard protocol and proper synthesis of results.

References

[1] Abellan van Kan G, Rolland Y, Andrieu S, Bauer J, Beauchet O, Bonnefoy M, et al. Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force. J Nutr Health Aging. 2009; 13:881–9. [PubMed: 19924348]

[2] Abramov, I., Gordon, J., Feldman, O. and Chavarga, A., 2012. Sex & vision I: Spatio-temporal resolution. Biology of Sex Differences, 3(1), pp.1-14.

[3] AlGheshyan, F.N., 2012. Comparison of ground reaction force in treadmill walking and in overground walking.

[4] Apkarian AV, Sosa Y, Krauss BR, Thomas PS, Fredrickson BE, Levy RE, Harden RN, Chialvo DR (2004) Chronic pain patients are impaired on an emotional decision-making task. Pain 108(1–2):129–136.

[5] AposTherapy® UK. (2017). Spatio-Temporal Parameters – What Do They Mean. [online] Available at: https://www.apostherapy.co.uk/blog/apostherapy/spatio-temporal-parameters-what-do-they-mean/ [Accessed 24 Aug. 2020].

Licensed Under Creative Commons Attribution CC BY

[6] Balshem, H., Helfand, M., Schünemann, H.J., Oxman, A.D., Kunz, R., Brozek, J., Vist, G.E., Falck-Ytter, Y., Meerpohl, J., Norris, S. and Guyatt, G.H., 2011. GRADE guidelines: 3. Rating the quality of evidence. Journal of clinical epidemiology, 64(4), pp.401-406.
[7] BONAB, M.A.R., Colak, T.K., Toktas, Z.O. and Konya, D., 2020. Assessment of Spatiotemporal Gait Parameters in Patients with Lumbar Disc Herniation and Patients with Chronic Mechanical Low Back Pain. Turkish Neurosurgery, 30(2), pp.277-284.
[8] Bowker, P. and Messenger, N., 1988. The measurement of gait.
[9] Carvalho AR, Andrade A, Peyré-Tartaruga LA. Possible changes in energy-minimizer mechanisms of locomotion due to chronic low back pain - a literature review. Rev Bras Reumatol. 2015;55(1):55-61. [Links]
[10] Cesari M, Kritchevsky SB, Penninx BW, Nicklas BJ, Simonsick EM, Newman AB, et al. Prognostic value of usual gait speed in well-functioning older people--results from the Health, Aging and Body Composition Study. J Am Geriatr Soc. 2005; 53:1675–80. [PubMed: 16181165]
[11] Chen, S.M., Liu, M.F., Cook, J., Bass, S. and Lo, S.K., 2009. Sedentary lifestyle as a risk factor for low back pain: a systematic review. International archives of occupational and environmental health, 82(7), pp.797-806.
[12] Christe, G., Kade, F., Jolles, B.M. and Favre, J., 2017. Chronic low back pain patients walk with locally altered spinal kinematics. Journal of biomechanics, 60, pp.211-218.
[13] Decety, J., Jeannerod, M. and Prablanc, C., 1989. The timing of mentally represented actions. Behavioural brain research, 34(1-2), pp.35-42.
[14] Delitto A, George SZ, Van Dillen LR, Whitman JM, Sowa G, Shekelle P, et al. Low back pain. J Orthop Sports Phys Ther 2012;42:A1–57.
[15] Demirel, A., Onan, D., Oz, M., Aslıyuce, Y.O. and Ulger, O., 2020. Moderate Disability Has Negative Effect on Spatiotemporal Parameters in Patients with Chronic Low Back Pain. Gait & Posture.
[16] Ebrahimi, S., Kamali, F., Razeghi, M. and Haghpanah, S.A., 2017. Comparison of the trunk-pelvis and lower extremities sagittal plane inter-segmental coordination and variability during walking in persons with and without chronic low back pain. Human movement science, 52, pp.55-66.
[17] Elbaz, A., Mirovsky, Y., Mor, A., Enosh, S., Debbi, E., Segal, G., Barzilay, Y. and Debi, R., 2009. A novel biomechanical device improves gait pattern in patient with chronic nonspecific low back pain. Spine, 34(15), pp.E507-E512.
[18] Ellingson LD, Koltyn KF, Kim J, Cook DB. Does exercise induce hypoalgesia through conditioned pain modulation? Psychophysiol 2014;51(3):267–76.
[19] Flor H, Braun C, Elbert T, Birbaumer N (1997) Extensive reorganization of primary somatosensory cortex in chronic back pain patients. Neurosci Lett 224(1):5–8
[20] Graci, V., Elliott, D.B. and Buckley, J.G., 2009. Peripheral visual cues affect minimum-foot-clearance during overground locomotion. Gait & posture, 30(3), pp.370-374.
[21] Ghamkhar L, Kahlaee AH. Trunk muscles activation pattern during walking in subjects with and without chronic low back pain: a systematic review. PM R. 2015;7(5):519-526. doi:10.1016/j.pmrj.2015.01.013
[22] Gombatto, S.P., Brock, T., DeLork, A., Jones, G., Madden, E. and Rinere, C., 2015. Lumbar spine kinematics during walking in people with and people without low back pain. Gait & posture, 42(4), pp.539-544.
[23] Goossens, N., Rummens, S., Janssens, L., Caeyenberghs, K. and Brumagne, S., 2018. Association between sensorimotor impairments and functional brain changes in patients with low back pain: a critical review. American journal of physical medicine & rehabilitation, 97(3), pp.200-211.
[24] Hanada, E.Y., Johnson, M. and Hubley-Kozey, C., 2011. A comparison of trunk muscle activation amplitudes during gait in older adults with and without chronic low back pain. PM & R, 3(10), pp.920-928.
[25] Henchoz Y, Soldini N, Peyrot N, Malatesta D. Energetics and mechanics of walking in patients with chronic low back pain and healthy matched controls. Eur J Appl Physiol. 2015;115(11):2433-43.
[26] Hartling, L., Milne, A., Hamm, M.P., Vandermeer, B., Ansari, M., Tsertsvadze, A. and Dryden, D.M., 2013. Testing the Newcastle Ottawa Scale showed low reliability between individual reviewers. Journal of clinical epidemiology, 66(9), pp.982-993.
[27] Hicks, G.E., Sions, J.M., Coyle, P.C. and Pohlig, R.T., 2017. Altered spatiotemporal characteristics of gait in older adults with chronic low back pain. Gait & posture, 55, pp.172-176.
[28] Hodges P. W., Tucker K. (2011). Moving differently in pain: a new theory to explain the adaptation to pain. Pain 152, S90–S8. 10.1016/j.pain.2010.10.020
[29] Hoy, D., Brooks, P., Blyth, F. and Buchbinder, R., 2010. The epidemiology of low back pain. Best practice & research Clinical rheumatology, 24(6), pp.769-781.
[30] J.M. VanSwearingen, S. Perera, J.S. Brach, R. Cham, C. Rosano, S.A. StudenskiA randomized trial of two forms of therapeutic activity to improve walking: effect on the energy cost of walking. J. Gerontol. A Biol. Sci. Med. Sci., 64 (2009), pp. 1190-1198
[31] Karayannis NV, Jull GA, Hodges PW. Physiotherapy movement based classification approaches to low back pain: comparison of subgroups through review and developer/expert survey. BMC MusculoskeletDisord2012;13:24.
[32] Kharb, A., Saini, V., Jain, Y.K. and Dhiman, S., 2011. A review of gait cycle and its parameters. IJCEM International Journal of Computational Engineering & Management, 13, pp.78-83.
[33] Koch, C. and Hänsel, F., 2018. Chronic non-specific low back pain and motor control during gait-A systematic review. Frontiers in psychology, 9, p.2236.
[34] Lamoth, C.J., Daffertshofer, A., Meijer, O.G. and Beek, P.J., 2006. How do persons with chronic low back pain speed up and slow down?: Trunk–pelvis coordination and lumbar erector spinae activity during gait. Gait & Posture, 23(2), pp.230-239.

Licensed Under Creative Commons Attribution CC BY

[35] Lamoth, C.J., Meijer, O.G., Daffertshofer, A., Wuisman, P.I. and Beek, P.J., 2006. Effects of chronic low back pain on trunk coordination and back muscle activity during walking: changes in motor control. European Spine Journal, 15(1), pp.23-40.
[36] Lamoth, C.J., Meijer, O.G., Wuisman, P.I., van Dieën, J.H., Levin, M.F. and Beek, P.J., 2002. Pelvis-thorax coordination in the transverse plane during walking in persons with nonspecific low back pain. Spine, 27(4), pp.E92-E99.
[37] Lee HS, Shim JS, Lee ST, et al. Facilitating effects of fast and slope walking on paraspinal muscles. Ann Rehabil Med 2014;38:514–22.
[38] Lee, C.E., Simmonds, M.J., Etnyre, B.R. and Morris, G.S., 2007. Influence of pain distribution on gait characteristics in patients with low back pain: part 1: vertical ground reaction force. Spine, 32(12), pp.1329-1336.
[39] Leisman, G., Moustafa, A.A. and Shafir, T., 2016. Thinking, walking, talking: integratory motor and cognitive brain function. Frontiers in public health, 4, p.94.
[40] Levine, R. V. and Norenzayan, A. (1999) 'The Pace of Life in 31 Countries', Journal of Cross-Cultural Psychology, 30(2), pp. 178–205.
[41] Lu, C.Y., 2009. Observational studies: a review of study designs, challenges and strategies to reduce confounding. International journal of clinical practice, 63(5), pp.691-697.
[42] Lund J, Donga R, Widmer C, Stohler C. The pain-adaptation model: A discussion of the relationship between chronic musculoskeletal pain and motor activity. Can J PhysiolPharmacol1991;69:683-694.
[43] M. Cesari, S.B. Kritchevsky, B.W. Penninx, B.J. Nicklas, E.M. Simonsick, A.B. Newman, et al.Prognostic value of usual gait speed in well-functioning older people–results from the Health, Aging and Body Composition Study. J. Am. Geriatr. Soc., 53 (2005), pp. 1675-1680
[44] Ma, L.L., Wang, Y.Y., Yang, Z.H., Huang, D., Weng, H. and Zeng, X.T., 2020. Methodological quality (risk of bias) assessment tools for primary and secondary medical studies: what are they and which is better?.Military Medical Research, 7(1), pp.1-11.. (n.d.). Chapter 10: Analysing data and undertaking meta-analyses.
[45] MacRae, C.S., Critchley, D., Lewis, J.S. and Shortland, A., 2018. Comparison of standing postural control and gait parameters in people with and without chronic low back pain: a cross-sectional case–control study. BMJ open sport & exercise medicine, 4(1).
[46] Mazzà, C., Iosa, M., Picerno, P. and Cappozzo, A., 2009. Gender differences in the control of the upper body accelerations during level walking. Gait & posture, 29(2), pp.300-303.
[47] Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Annals of internal medicine. 151:264-269, 2009
[48] Moseley GL (2008) Pain, brain imaging and physiotherapy–opportunity is knocking. Manual Therap 13(6):475–477.
[49] Muller R, Ertelt T, Blickhan R. Low back pain affects trunk as well as lower limb movements during walking and running. J Biomech2015;48:1009–14
[50] Murray J. McAllister, P., 2020. Central Sensitization. [online] Instituteforchronicpain.org.
[51] Müller, R., Ertelt, T. and Blickhan, R., 2015. Low back pain affects trunk as well as lower limb movements during walking and running. Journal of biomechanics, 48(6), pp.1009-1014.
[52] neuromuscular measures of function in patients with adult degenerative scoliosis,
[53] Newell, D. and van der Laan, M., 2010. Measures of complexity during walking in chronic non-specific low back pain patients. Clinical Chiropractic, 13(1), pp.8-14.
[54] Pontzer, H., Raichlen, D.A. and Sockol, M.D., 2009. The metabolic cost of walking in humans, chimpanzees, and early hominins. Journal of Human Evolution, 56(1), pp.43-54.
[55] R. Haddas, I.H. Lieberman, A. Block, The relationship between fear-avoidance and
[56] Riener, C.R., Witt, J.K., Stefanucci, J.K. and Proffitt, D.R., 2005. Seeing beyond the target: An effect of environmental context on distance perception. Journal of Vision, 5(8), pp.195-195.
[57] Roland M. A critical review of the evidence for a pain-spasm-pain cycle in spinal disorders. Clin Biomech1986;1:102-109. 22.
[58] S. Studenski, S. Perera, K. Patel, C. Rosano, K. Faulkner, M. Inzitari, et al.Gait speed and survival in older adults. JAMA, 305 (2011), pp. 50-58
[59] S.M. Al-Obaidi, B. Al-Zoabi, N. Al-Shuwaie, N. Al-Zaabie, R.M. Nelson, The influence of pain and pain-related fear and disability beliefs on walking velocity in chronic low back pain, Int. J. Rehabil. Res. 26 (2) (2003) 101–108
[60] Spine (Phila Pa 1976) 43 (23) (2018) E1412–e21,
[61] Studenski S, Perera S, Patel K, Rosano C, Faulkner K, Inzitari M, et al. Gait speed and survival in older adults. Jama. 2011; 305:50–8. [PubMed: 21205966]
[62] Suh, J.H., Kim, H., Jung, G.P., Ko, J.Y. and Ryu, J.S., 2019. The effect of lumbar stabilization and walking exercises on chronic low back pain: A randomized controlled trial. Medicine, 98(26).
[63] Van den Hoorn, W., Bruijn, S.M., Meijer, O.G., Hodges, P.W. and Van Dieën, J.H., 2012. Mechanical coupling between transverse plane pelvis and thorax rotations during gait is higher in people with low back pain. Journal of biomechanics, 45(2), pp.342-347.
[64] van Dieën, J.H., Selen, L.P. and Cholewicki, J., 2003. Trunk muscle activation in low-back pain patients, an analysis of the literature. Journal of electromyography and kinesiology, 13(4), pp.333-351.
[65] Van Dillen LR, Sahrmann SA, Norton BJ, Caldwell CA, McDonnell MK, Bloom N. The effect of modifying patient-preferred spinal movement and alignment during symptom testing in patients with low back pain: a preliminary report. Arch Phys Med Rehabil2003;84:313–22.
[66] Vogt, L., Pfeifer, K. and Banzer, W., 2003. Neuromuscular control of walking with chronic low-back pain. Manual therapy, 8(1), pp.21-28.

Licensed Under Creative Commons Attribution CC BY

[67] Y. Barzilay, G. Segal, R. Lotan, G. Regev, Y. Beer, B.S. Lonner, et al., Patients with chronic non-specific low back pain who reported reduction in pain and improvement in function also demonstrated an improvement in gait pattern, Eur. Spine J. 25 (9) (2016) 2761–2766

[68] Zahraee, M.H., Karimi, M.T., Mostamand, J. and Fatoye, F., 2014. Analysis of asymmetry of the forces applied on the lower limb in subjects with nonspecific chronic low back pain. BioMed research international, 2014.

Licensed Under Creative Commons Attribution CC BY