Spine and Pelvis Coordination Variability in Rowers with and without Chronic Low Back Pain during Rowing

Elham Alijanpour[1], Ali Abbasi[1]*, Robert A. Needham[2], Roozbeh Naemi[2]

1. Department of Biomechanics and Sports Injuries, Faculty of Physical Education and Sports Sciences, Kharazmi University, Tehran, Iran
2. Centre for Biomechanics and Rehabilitation Technologies, School of Life Sciences and Education, Staffordshire University, Science Centre Leek Road Stoke on Trent, ST4 2DF UK

* Corresponding author: Ali Abbasi, Department of Biomechanics and Sports Injuries, Faculty of Physical Education and Sports Sciences, Kharazmi University, Tehran, Iran.

Tel: +989127305114

Email: abbasi@khu.ac.ir ; abbasi.bio@gmail.com

Word counts: 3528 without abstract and references

Abstract

The aim of this study was to compare the spine-pelvis coordination and coordination variability (CV) during rowing in elite rowers with and without chronic low back pain (CLBP). Fourteen professional rowers (6 healthy and 8 with CLBP) participated in this study. 3D kinematic of upper trunk (UT), lower trunk (LT), lower back (LB), and pelvis segments during ergometer rowing at 70% and 100% of peak power were captured. The adjacent segments' coordination and CV were calculated using modified vector coding method. The results showed that segments' range of motion increased in both groups with increasing intensity, especially in CLBP rowers. CLBP rowers showed significantly lower: LT dominancy in LT/LB coordination at both intensities; anti-phase pattern in LB/Pelvis coordination at 100% intensity; UT/LT CV in early recovery, and significantly higher LB/Pelvis CV in final recovery and catch position ($p<0.05$). Moreover, both groups showed significantly lower UT dominancy for UT/LT coordination in sagittal plane; higher anti-phase pattern in frontal plane; lower UT/LT CV in sagittal plane, lower LT/LB CV in sagittal and transverse plane, lower LB/Pelvis CV in frontal plane in trunk preparation phase, and a lower UT/LT CV in frontal plane for acceleration phase at 100% versus 70% intensity. In conclusion rowers with CLBP cannot adapt their coordination pattern and its variability with increase in intensity, and the movement in the kinematic chain from pelvis to UT stops in spine-pelvic junction. These findings have practical implications in designing coaching and rehabilitation strategies to facilitate performance and prevent injuries.

Keywords: Coordination, Variability, Spine, Low Back Pain, Rowing

1. Introduction

Low back pain (LBP) is the most prevalent injury in rowers (Newlands et al., 2015; Ng et al., 2014; Wilson et al., 2010). Repetitive nature of rowing coupled with training volume, poor kinematics, previous history of LBP (Newlands et al., 2015; Teitz et al., 2003), repetitive mechanical strain (Trompeter et al., 2017), the volume of ergometer training (Ng et al., 2014; Wilson et al., 2010), and poor body position (Thornton et al., 2017) can enhance the risk of LBP in rowers. Several studies focused on pelvis and spinal kinematics during rowing to find the cause of LBP (Holt et al., 2003; McGregor et al., 2004; Ng et al., 2015; Steer et al., 2006). However, these studies considered spine as single-segment, whereas recent researches showed that lower and upper parts of spine can move differently (Christe et al., 2017, 2016; Leardini et al., 2011; Needham et al., 2016). Specifically, altered upper and lower spine kinematics have reported in participants with chronic low back pain (CLBP) during gait (Crosbie et al., 2013) and sit to stand task (Christe et al., 2016). These indicate the importance of multi-segmental spine kinematics examination in these group of individual patients that is necessary to provide new insights regarding therapeutic interventions.

The majority of studies on spine and pelvis kinematics have used traditional linear analysis methods. Recently, nonlinear analysis methods such as continuous relative phase and vector coding have become popular choices due to the detail these techniques provide on the coordination pattern and coordination variability between joints or segments (Abbasi et al., 2020; Mehri et al., 2020; Needham et al., 2020, 2015). However, vector coding is often preferred since this technique provides more intuitive information in a clinical setting (Needham et al., 2014; Seay et al., 2011). Vector coding quantifies the vector orientation between adjacent data points on an angle-angle plot relative to right horizontal. The outcome measure is referred to as the coupling angle that can be assigned to a coordination pattern, which classifies the movement between segments as either in-phase (move in the same direction) or anti-phase (move in opposite direction). The classification can also infer on proximal or distal segment dominancy (Needham et al., 2020).

Stroke phases of rowing compose of drive and recovery phases which the segments movement pattern can be considered as similar to the pattern of sit to stand (Kerr et al., 1997) and lifting (Pries et al., 2015). During drive phase, same as rising phase in sit to stand, a distal to proximal extension sequencing in pelvis, lower back, lower thoracic, and upper thoracic with an in-phase coordination pattern need to transit force of lower extremities to upper body and roar optimally. During recovery phase, same as descending phase in sit to stand, however, it changes to a proximal to distal flexion sequencing with an in-phase coordination pattern to reach full flexion position and prepare for next rowing cycle (Kerr et al., 1997). This is the preferred motor strategy in sagittal plane to enhance rowing performance and reduce the risk of injuries in rowers. Any change in this coupling strategy can increase demands on other segments, impair performance, and increase the risk for overuse injuries in pelvis-spine. For instance, more lumbar flexion during fatiguing ergometer rowing have reported to increase the risk for lower back injury in rowers (Holt et al., 2003; McGregor et al., 2007; Minnock, 2017; Wilson et al., 2013).

A recent systematic review on the relationship between rowing-related low back pain and rowing biomechanics, identified distinct kinematic characteristics on lower with low back pain compared to healthy (Nugent et al., 2021). Despite this, there is a scarcity of studies in which the coordination and coordination variability of the spine is considered in relation to low back pain in rowers and the distinct coordination pattern of rowers against healthy rowers has not been commonly studied.

The investigation of spine-pelvis coordination via vector coding has noted differences between healthy and LBP patients during walking (Seay et al., 2011), running (Pelegrinelli et al., 2020;

Seay et al., 2011), and lifting (Pries et al., 2015). However, the investigation of CV between the spine and pelvis in healthy rowers is limited to a single study and analysis in the sagittal plane (Minnock, 2017). The authors suggested that thoracic-lumbar CV did not differ between different intensities, but lumbar-pelvis CV significantly decreased in 80% intensity in recovery-drive phase of rowing. Although the main movement in rowing is in the sagittal plane, low back pain can be expected to cause compensation movement in frontal and transverse planes of spine and pelvis during rowing (Wilson et al., 2010) and running (Pelegrinelli et al., 2020). However, the coordination and its variability in the three plane of movement have not been previously investigated in rowing. Hence, the aim of this study was to investigate and compare the spine-pelvis coordination and CV during rowing at maximal and sub-maximal intensities in rowers with & without CLBP. We hypothesized that 1) segments' ROM significantly differ between CLBP and healthy groups and increase in higher rowing intensity, 2) coordination in the spine and pelvis segments differ between healthy and CLBP rowers during rowing on an ergometer at different intensities, 3) CLBP rowers have greater CV compared to healthy rowers, 4) the CVs reduced with increase in intensity in both group.

2. Methods

2.1. Participants

Ethical approval was granted from Kharazmi University Institutional Review Board. Participants in this study were recruited from members of the national rowing team who were in preparation camp for 2020 Olympic Games and regularly practiced every day. Following the written informed consent, the participants answered pain scale questionnaire and those who had the score equal or greater than 3 on the ten-point scale for more than 3 months assigned in CLBP (Balagué et al., 2012; Christe et al., 2017) and others were assigned in healthy group (HG) (Table 1). Healthy participants were not eligible to participate in the study if they had any other major injuries and if they had ever received back surgery within the previous one year. CLBP participants were eligible if they did not have any other injuries except CLBP.

Table 1 about here

2.2. Experimental setup

A seven-camera motion capture system (Vero 2.2, VICON, Oxford, UK) was used to record kinematic data with a sampling rate of 200 Hz following calibration according to the manufacturer's instruction. A concept II rowing ergometer (Concept Inc., Morrisville, Vermont) was placed in the center of the room (Figure 1). Three clusters were placed on the spinous process of T3, T8 and L3 to track movement in the upper thoracic (UT), lower thoracic (LT) and lower back (LB) of the spine, respectively. Four markers were placed on anterior superior iliac spine and posterior superior iliac spine bilaterally to track the pelvis segment (Needham et al., 2016). One marker was placed on the handle of ergometer for rowing cycle identification. The participant stood in an anatomical position to record the static test. Then, they completed a 5-minute warm-up on the rowing ergometer. During the main test, they performed an incremental step-test (70% up to 100% of their peak power intensity, 30 second rowing at 16 revolution per minute (RPM) with 30 second rest between each intensity) on the rowing ergometer and kinematic data were collected over every 30 seconds at each intensity of 70% and 100% (Minnock, 2017).

Figure 1 about here

2.3. Data processing

Kinematics trajectories were low pass filtered with a zero lag fourth-order Butterworth filter with a cut off frequency of 6 Hz. Cycles identification were obtained by maximum and minimum values of a trajectory of handle's marker in Y-axis (anterior-posterior) in Nexus 2.8.2 software. Three-dimensional angles of UT, LT, LB, and pelvis relative to the global coordinate system were calculated in Procalc 2.1.2 software according to the method presented elsewhere (Needham et al., 2014). Drive and recovery phases for each cycle were separately normalized to 50 points and time normalized to 100% of the rowing stroke; so, the first point of each normalized cycle was catch position and 50th point was finish position (figure 2).

Figure 2 about here

2.4.Data analysis

To determine segments ROM, the minimum value was subtracted from the maximum value for each stroke cycle in all three planes and then averaged across five cycles at each intensity. Segment coordination, and CV were calculated for five cycles at intensities of 70% and 100% using a modified vector coding technique (Needham et al., 2014, 2020). As rowing performance might not be steady at the start and finish of rowing performance, these cycles were taken from the middle of the sequence. Coordination patterns were classified into in-phase with proximal dominancy (IPPD), in-phase with distal dominancy (IPDD), anti-phase with proximal dominancy (APPD), and anti-phase with distal dominancy (APDD) (Needham et al., 2015). The percentage of rowing stroke from each coordination pattern were quantified using frequency plots to understand the most prevalent patterns. CV was calculated as the standard deviation of the vector connecting corresponding consecutive time points of the angle-angle plots across all cycles. The UT/LT, LT/LB, LB/Pelvis coordination and CV were examined in sagittal, frontal, and horizontal planes.

2.5.Statistical analysis

Normality of ROM and coordination pattern frequency data was indicated with Kolmogorov-Smirnov test. Hence the differences in ROM and coordination pattern frequencies in both groups and intensities were assessed with two-way repeated measure ANOVA using SPSS (IBM SPSS statistics 22, SPSS Inc., Chicago, IL). A statistical parametric mapping (SPM) two-way repeated-measures ANOVA and paired sample t-test and independent t-test (as post-hoc tests) were used to detect significant differences between CV waveforms taking two groups and the intensities (v.M0.1, www.spm1d.org). The statistical significance level for all analyses was set at $p = 0.05$.

3. Results

3-1. ROM results

The LB ROM in transverse plane at 100% intensity was significantly ($p < 0.05$) lower in HG compared to CLBP group. No other significant differences in any segment's ROM was observed between the HG and CLBP group. With regards to segmental ROM at different intensities, the HG at 100% intensity showed significantly ($p<0.05$) higher UT and LT ROMs in sagittal plane and significantly ($p<0.05$) higher LT ROM in frontal plane compared to 70% intensity. In addition, the CLBP group showed a significantly ($p<0.05$) higher ROM in both LB and LT at 100% intensity compared to 70% intensity (Table 2). No other significant differences in any segment's ROM was observed between the two intensities in either groups.

Table 2 about here

3-2. Coordination results

The results of UT/LT showed that IPPD frequency in sagittal plane significantly ($p<0.05$) decreased with intensity increasing in both groups for trunk preparation, final recovery, blade entry and rower's acceleration phases. The APDD frequency in frontal plane significantly ($p<0.05$) increased with intensity increasing in both groups (Figure 3).

Figure 3 about here

The results of LT/LB showed that IPPD frequency in sagittal plane significantly ($p<0.05$) decreased in CLBP compared to healthy rowers at both intensities for the boat roll-out, blade extraction, and early recovery phases (Figure 4).

Figure 4 about here

The results of LB/Pelvis showed that APPD frequency in sagittal plane significantly ($p<0.05$) increased with intensity increasing in HG for final recovery and blade entry phases. The APDD frequency in frontal plane significantly ($p<0.05$) increased with intensity increasing in both groups (Figure 5). However, there were no significant differences in coordination between intensities for either groups in transverse plane for UT/LT, LT/LB, and LB/Pelvis ($p > 0.05$).

Figure 5 about here

3-3. Coordination variability

In sagittal plane, the UT/LT CV significantly decreased in HG with intensity increasing for end of early recovery and trunk preparation phases ($p < 0.05$). In frontal plane, the UT/LT CV significantly ($p<0.05$) decreased with intensity increasing in both groups at acceleration phase and increased in HG at 70% compared to 100% intensity, but in CLBP rowers it showed the opposite trend in early recovery phase ($p < 0.05$), however, the results of post-hoc did not show any significant differences between groups and intensities ($p > 0.05$). Moreover, in trunk preparation phases, CLBP rowers showed significantly decreased CV at 70% compared to 100% intensity and

HG showed significantly decreased CV at 100% compared to 70% intensity. In transverse plane, the UT/LT CV significantly ($p<0.05$) decreased in HG at 100% compared to 70% intensity in early recovery and trunk preparation phases and it significantly decreased in CLBP group at 100% compared to 70% intensity in trunk preparation phase (Figure 6a).

The LT/LB CV significantly decreased at 100% compared to 70% intensity in HG for trunk preparation phase in sagittal and transverse planes ($p < 0.05$), However, it did not show any significant difference between the two intensities in frontal plane (Figure 6b).

CLBP rowers showed significantly increased LB/Pelvis CV at 100% compared to 70% intensity in sagittal plane for final recovery phase and catch position ($p < 0.05$), and they showed significantly ($p<0.05$) increased CV at 100% compared to 70% intensity in frontal plane for trunk preparation phase. However, the CLBP group did not show any significant differences in CV at transverse plane between different intensities (Figure 6c).

Figure 6 *about here*

4. Discussion

4.1 Comparison of ROM between healthy and CLBP

The results showed that only LB ROM at 100% intensity in transverse plane showed to be significantly higher in CLBP group compared to HG. Moreover, increasing intensity significantly increased UT ROM in healthy, LT ROM in both groups, LB ROM in CLBP in sagittal plane, and LT ROM in healthy group in frontal plane. The ROM increased sequentially from pelvis to UT at both intensities and this increase was more at 100% intensity, especially in the CLBP group. This is in line with the previous findings by Wilson et al. (2012) who found that in healthy elite rowers, an increase in intensity led to an increase in frontal lumbar motion. The healthy rowers showed an increase in spine ROM and a decrease in pelvis ROM in the transverse plane with an increase in intensity, but the CLBP rowers showed a decreased UT and LT ROM and increased LB and pelvis ROM in higher rowing intensity. However none of these mentioned changes were statistically significant. Also, our result are in line with another study which reported that rowers with LBP had greater lower back flexion compared to healthy rowers (Ng et al., 2015). It seems CLBP rowers increase pelvis and LB ROM compared to upper spine parts in higher rowing intensity.

4.2 Comparison of coordination patterns between groups and intensities

In the current study, the coordination pattern between the spine and pelvis segments differed between healthy and CLBP rowers and across different intensities during ergometer rowing, thus accepting the second hypothesis. In relation to coordination pattern at 70% intensity, for both CLBP and healthy, the coordination pattern of both UT/LT and LT/LB in the sagittal plane was on average IPDD. However by increasing intensity to 100%, in healthy group the distal dominancy significantly increased, but in CLBP group the distal dominancy significantly decreased. The coordination pattern of UT/LT in the sagittal plane was on average IPDD, especially in the healthy group. Also, as the intensity increased there was an increase in UT dominancy in both groups during trunk preparation, final recovery, blade entry, and acceleration phases (Figure 3). An increase in UT dominancy in the healthy group suggested that with an increase in intensity, UT moves further compared to LT in order to transmit the movement to the upper extremity and to achieve the best position for blade entry. In a previous study CLBP patients reported to adopt a stable trunk movement over long periods of flexion-extension movement at different speeds compared to the healthy group (Asgari et al., 2015). Furthermore, Tsang et al. (2017) reported that compared to the healthy group, the LBP group did not alter movement strategies based on a change in the task and speed of movement (Tsang et al., 2017). In line with the previous findings, our results showed that UT and LT ROM increased as a result of an increase in intensity, which was more notable in the healthy group (Table 1). Therefore, this observation suggests that CLBP rowers cannot adapt their UT/LT coordination at higher rowing intensities to efficiently transmit the movement from distal to proximal segments in the spine kinematic chain like the healthy rowers.

The coordination pattern of LT/LB in the sagittal plane was IPPD, specifically in healthy rowers (Figure 4) which suggests LT movement was greater than LB. This finding is similar to the result of previous study in which a LT dominancy in healthy elite rowers was reported (Minnock, 2017). Results of the current study showed LT dominancy was significantly decreased with an increase in intensity among the CLBP rowers compared to the HG. Unlike our results, Minnok et al. (2017) showed that while LT was the dominant segment at 70% intensity, LB became the dominant segment at 100% intensity (Minnock, 2017). However, this discrepancy may be a result of different motion capture systems used to measure segmental angles in our study (Vicon system and marker clusters) and Minnok (2017) study (IMU system). Furthermore, our results showed that LT dominancy in the CLBP rowers was significantly lower compared to the HG at both intensities for the boat roll out, blade extraction, and early recovery phases. The trunk is in a vertical position at the beginning of the boat roll out and it moves backward till the blade extraction phase and it is almost fully extended. Blade extraction leads to the beginning of the trunk forward movement and then the trunk and pelvis move forward following the handle movement in the early recovery phase (Kleshnev, 2016). Less movement of LB compared to LT from boat roll out to finish position in healthy rowers suggests a support role of the lower segment for a transition of the movement from lower to upper segments. Decreased LT dominancy in the CLBP rowers suggests that they cannot transit the movement to upper segments efficiently and that they cannot use the LB as a support segment.

The coordination pattern of LB/Pelvis in the sagittal plane was IPPD (Figure 5) that is similar to previous results (Minnock, 2017). Moreover, healthy group demonstrated an APPD with an intensity increasing. This is as a result of lumbar flexion and pelvis posterior tilt in the final recovery and blade entry phases. This finding is similar to previous study that reported more anti-phase pattern of the LB to pelvis in healthy participants during gait (Seay et al., 2011). This pattern can help rowers to change their lower back from flexion to extension with pelvis support. However, the CLBP rowers did not show this pattern and this could have affected their performance.

The distribution of coordination did not follow any special pattern in frontal and transverse planes and coupling phase and segment dominancy was almost equal in all phases of rowing (Figures 3, 4, and 5). This consistency in coordination and segment dominancy can be useful for rowers, as it causes the symmetrical distribution of tensile and compressive loads on both sides of the spine and pelvis. However, the APDD coordination pattern in UT/LT and LB/Pelvis were increased by an increase in intensity in both groups (Figure 3, 5). This can increase compressive load on one side of the vertebra and tensile load on another side and it may increase the risk of injuries in the spine.

4.3 Comparison of coordination variability between groups and intensities

The results showed that there was greater variability in the sagittal plane in either groups or at either intensities in blade extraction and first of early recovery (transition from drive to recovery), and final recovery and blade entry (transition from recovery to drive). Therefore, the CV increased due to a change in segment dominancy and coordination patterns. CLBP rowers exhibited greater CV in the sagittal plane at the 70% intensity from the initial acceleration phase to the end of blade extraction phase, partially supporting our third hypothesis. The CV was around 10 to 20 degrees which presents a change in segment dominancy. This suggests that CLBP rowers change segment dominancy to find a more pain-free pattern. This finding is in line with the findings by Jeweel et al. (2018) which reported greater CV in sagittal plane at the beginning of prolonged running on treadmill in runners with patellofemoral pain syndrome (PFPS) compared to the healthy group (Jewell et al., 2018). It was also observed that CV reduced at the end of running by an increase of pain (Jewell et al., 2018), but one of limitation of the current study is that pain was not monitored during the test. Nevertheless, the reduction of CV by an intensity increasing in CLBP rowers suggests that they cannot change segment dominancy to reduce the pain over the incremental step-test.

The results of the current study showed CV in the frontal and transverse planes were greater compared to the sagittal plane for all couples in either groups and at both intensities. This can suggest that a high amount of CV in frontal and transverse planes can help rowers to distribute the loads on more surrounded tissues. It was also observed that most of the significant differences in CV occurred in early recovery and trunk preparation that the rowers must control the velocity and acceleration based on stroke rate in these phases (Kleshnev, 2016). The CV of UT/LT and LT/LB in sagittal plane and LT/LB in transverse plane in healthy rowers and LB/Pelvis CV in frontal plane in CLBP rowers were decreased with an intensity increasing in these phases, partially supporting our fourth hypothesis. This suggests that healthy rowers can achieve optimum stroke rate by an increase in the CV and distribute perturbations on more surrounded tissues in low intensity. But CV decreased in high intensity because rowers do not seem to control the seat velocity. Also, UT/LT CV decreased in both groups at the transverse plane and it increased in healthy but decreased in CLBP rowers in frontal plane in trunk preparation phase at higher intensity. This can suggest that CLBP rowers cannot distribute perturbations in the tissues to control the stroke rate in greater rowing intensity. Furthermore, LB/Pelvis CV in the sagittal plane at 100% intensity for final recovery phase and catch position significantly increased in the CLBP group compared to the healthy rowers. In fact, the spine is in full flexion in this short phase and cannot make greater movement (Kleshnev, 2016), thus the increase of CV in the CLBP rowers can present a poor technique in these athletes that may be as a results of low back pain (Thornton et al., 2017).

In conclusion, healthy rowers showed an increased spine movement and a reduced pelvis movement to distribute the load on more surrounded tissues in the spine with pelvis support. Also, CLBP rowers showed not to be able to adapt their coordination pattern and CV with an increase in intensity where the kinematic chain from the pelvis to UT stopped in the spine-pelvis junction. This is contrary to healthy rowers that showed to be able to transfer movement in the kinematic chain from the pelvis to UT in high-intensity with no discontinuity between pelvis to UT. Moreover, CLBP rowers cannot use the lower segment as a support for upper segment to transit the movement from lower segment to upper segment in the kinematic chain.

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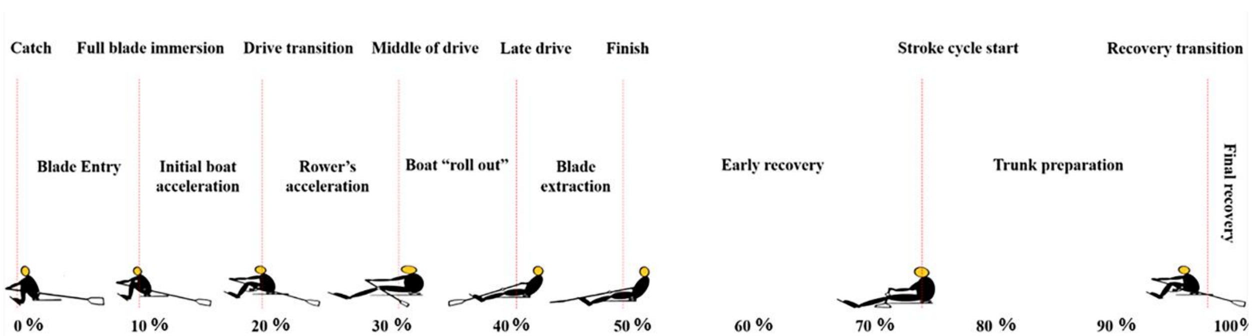

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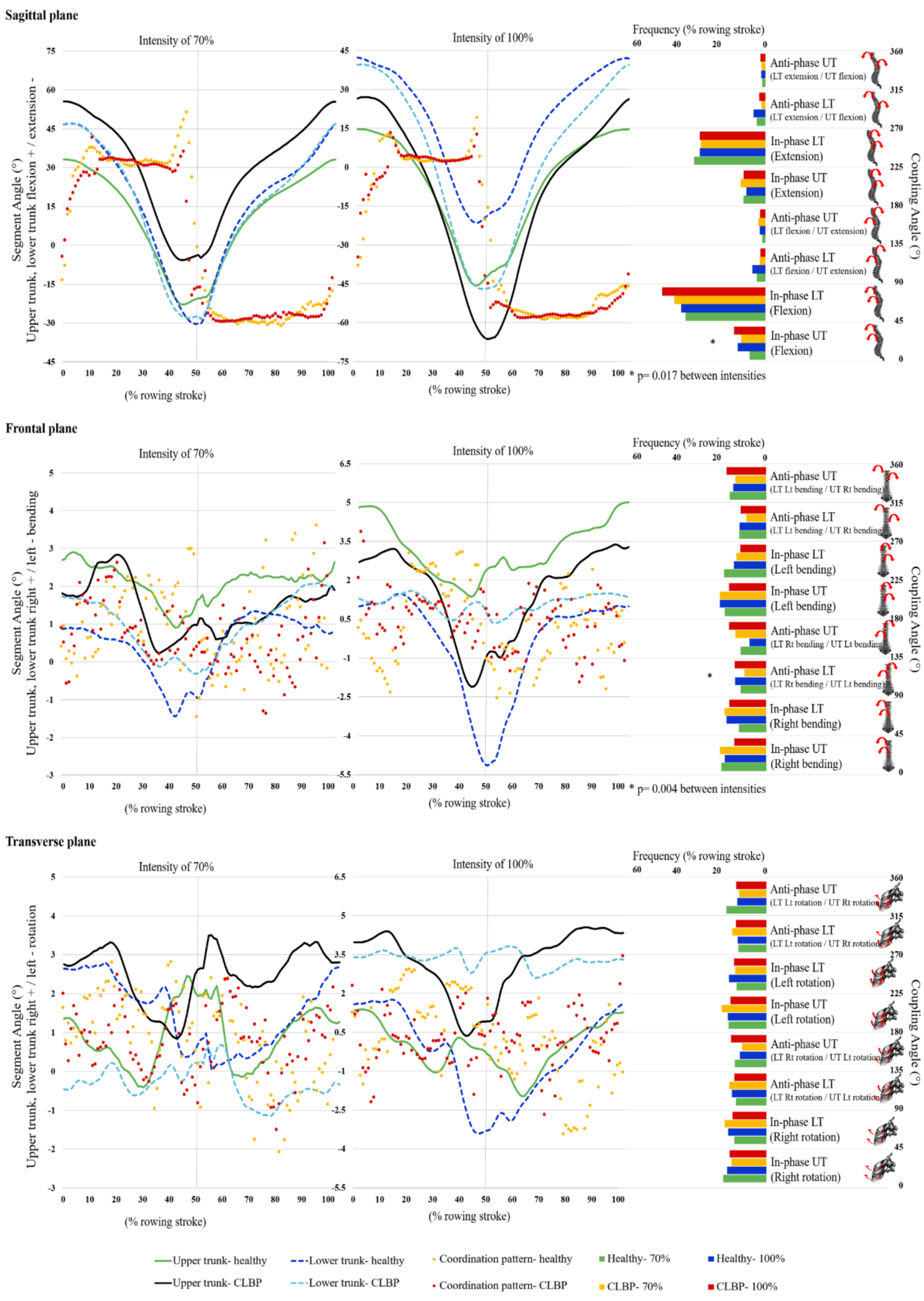

454 Figure 4: LT/LB segments angular displacement diagram in sagittal, frontal and transverse planes and the

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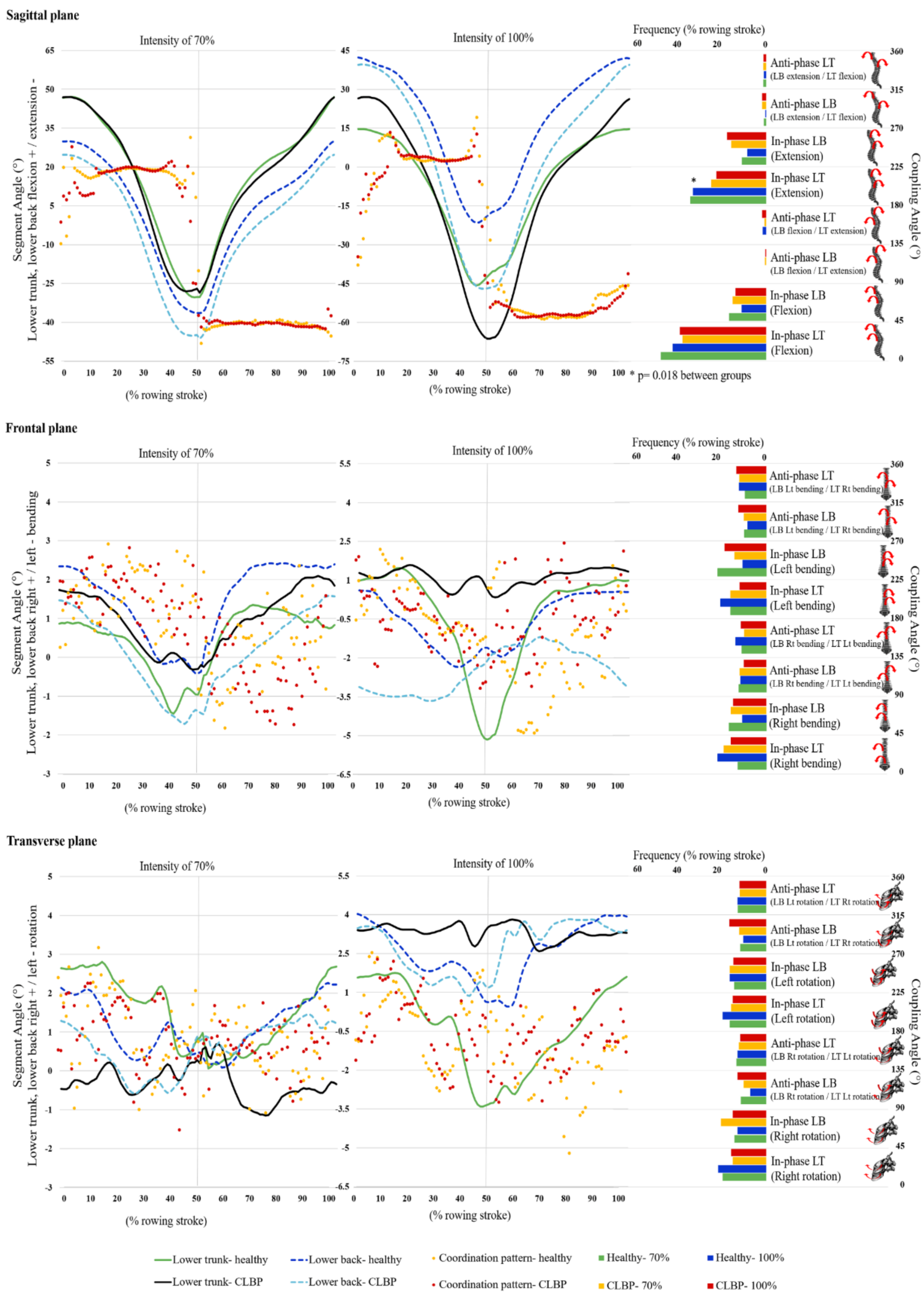

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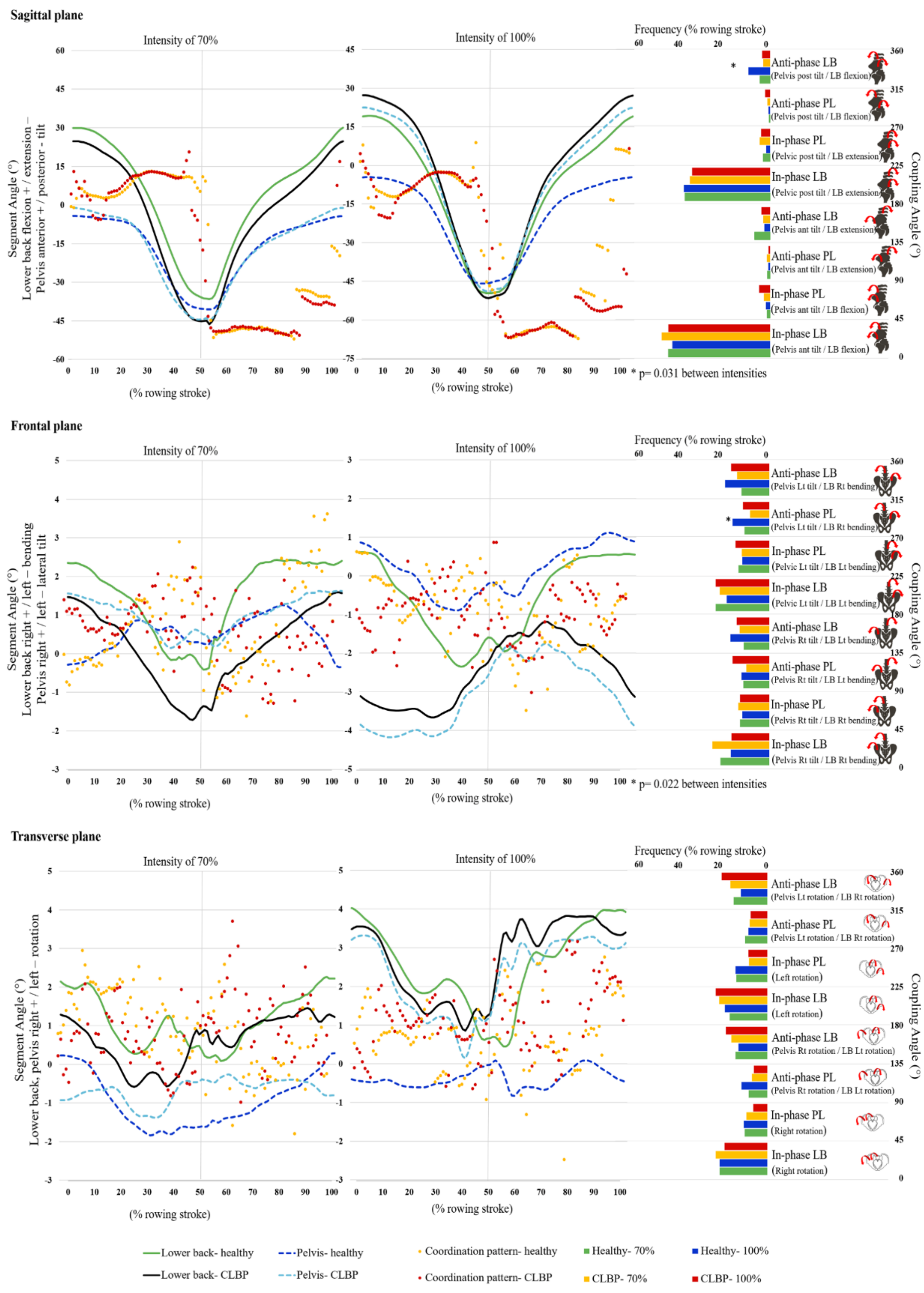

Figure 6: a) UT/LT CV, b) LT/LB CV, c) LB/Pelvis CV in sagittal, frontal and transverse planes

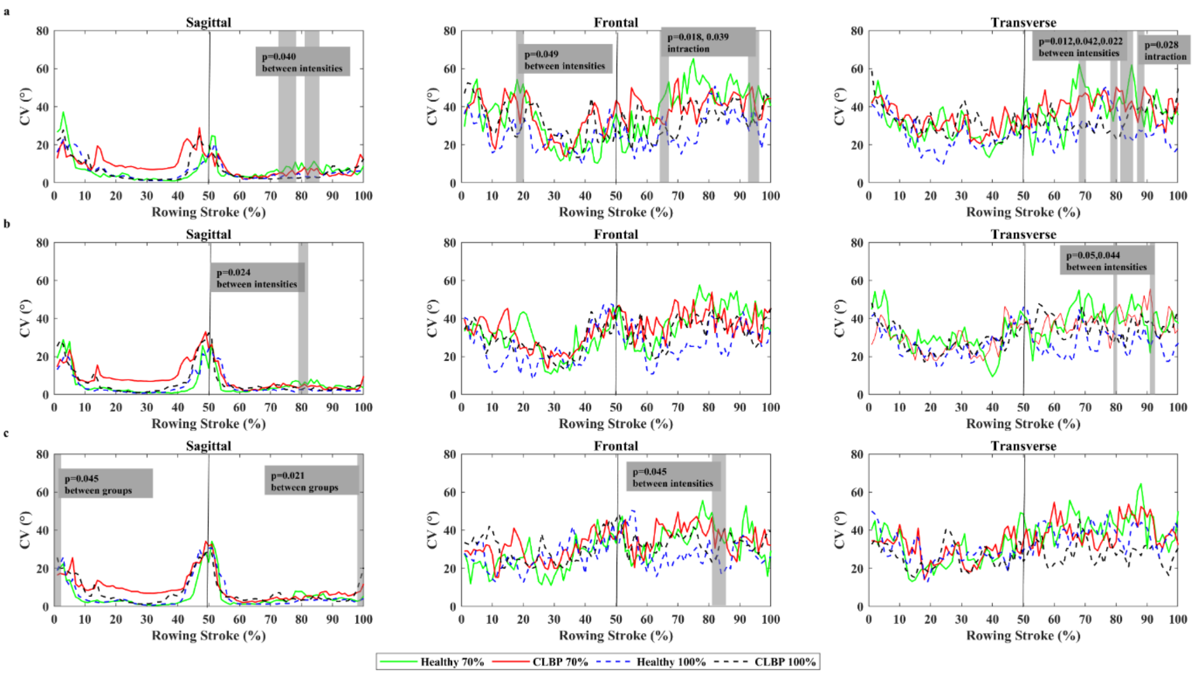

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Table 1: The demographic information of participants

Group	females	males	Age (year)	Mass (kg)	Height (cm)	Rowing experience (year)
Healthy	3	3	25.03±4.50	70.83±14.60	180.16±9.72	5.83±2.71
CLBP	4	4	24.12±4.90	77.87±13.20	183.25±9.10	6.53±4.02

Table 2: mean and standard deviation of range of motion in all segments

Segments	Groups	Sagittal plane			Frontal plane			Transverse plane		
		70%	100%	P value	70%	100%	P value	70%	100%	P value
Upper trunk (degree)	Healthy	57.85±20.23	64.09±18.62	0.002*	5.23±2.50	8.23±4.70	0.221	6.89±2.42	9.21±5.24	0.384
	CLBP	63.31±11.54	65.58±11.19	0.527	5.69±2.02	10.16±8.35	0.136	12.20±10.60	8.73±3.91	0.464
	P value	0.534	0.854		0.710	0.623		0.256	0.848	
Lower trunk (degree)	Healthy	77.95±3.87	94.58±15.50	0.041*	4.18±1.86	7.76±3.75	0.045*	5.99±2.94	8.62±6.16	0.183
	CLBP	78.14±7.29	87.47±3.48	0.002*	4.73±1.63	5.44±3.19	0.528	6.90±1.80	6.88±2.17	0.964
	P value	0.954	0.317		0.569	0.232		0.480	0.470	
Lower back (degree)	Healthy	66.95±9.54	69.98±9.58	0.122	4.19±1.52	4.21±2.33	0.963	4.53±1.65	5.71±3.28	0.514
	CLBP	72.34±11.87	80.28±11.32	0.018*	4.37±2.09	5.91±3.18	0.215	7.42±2.2	10.09±2.77	0.086
	P value	0.381	0.098		0.857	0.293		0.20	0.019**	
Pelvis (degree)	Healthy	37.06±8.94	35.03±9.55	0.326	2.79±0.82	3.13±1.52	0.612	3.06±1.75	2.88±0.94	0.739
	CLBP	45.50±11.99	45.52±12.38	0.992	2.91±1.66	4.37±2.35	0.153	3.12±1.22	3.94±1.76	0.125
	P value	0.175	0.111		0.881	0.282		0.943	0.196	

* Significant differences between intensities, ** Significant differences between groups