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Multi-segment spine kinematics: Relationship with dance training and low back pain

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ABSTRACT

Background: Spine posture, range of motion (ROM) and movement asymmetry can contribute to low back pain (LBP). These variables may have greater impact in populations required to perform repetitive spine movements, such as dancers; however, there is limited evidence to support this.
Research question: What is the influence of dance and LBP on spinal kinematics?
Methods: In this cross-sectional study, multi-segment spinal kinematics were examined in 60 female participants, including dancers (n = 21) and non-dancers (n = 39) with LBP (n = 33) and without LBP (n = 27). A nine-camera motion analysis system sampling at 100 Hz was used to assess standing posture, as well as ROM and movement asymmetry for side bend and trunk rotation tasks. A two-way ANOVA was performed for each of the outcome variables to detect any differences between dancers and non-dancers, or individuals with and without LBP.
Results: Compared to non-dancers, dancers displayed a flatter upper lumbar angle when standing ($p < 0.01$, $\eta p^2 = 0.15$), and achieved greater frontal plane ROM for the upper lumbar ($p = 0.04$, $\eta p^2 = 0.08$) and lower thoracic ($p = 0.02$, $\eta p^2 = 0.09$) segments. There were no differences between dancers and non-dancers for transverse plane ROM ($p > 0.05$) or movement asymmetry ($p > 0.05$). There was no main effect for LBP symptoms on any kinematic measures, and no interaction effect for dance group and LBP on spinal kinematics ($p > 0.05$).
Significance: Female dancers displayed a flatter spine posture and increased spine ROM compared to non-dancers for a select number of spine segments and movement tasks. However, the overall number of differences was small, and no relationship was observed between LBP and spinal kinematics. This suggests that these simple, static posture, ROM, and asymmetry measures often used in clinical practice can provide only limited generalisable information about the impact of dance or LBP on spinal kinematics.

1. Introduction

Alongside biological and psychosocial factors, biomechanical factors can contribute to the initiation and persistence of low back pain (LBP) [1]. Prospectively, a flatter standing posture as well as reduced spine mobility have been seen to precede more serious episodes of first time LBP [2]. Furthermore, individuals with existing LBP commonly present with reduced lumbar spine range of motion (ROM), as well as more asymmetrical spine movement, compared to persons without [3,4]. Accordingly, assessment of spinal posture and movement is a common component of clinical examination for LBP patients and can inform treatment strategy [5,6].

It is possible that the contribution of biomechanical factors on the development of LBP is of greater importance in populations with large movement demands [2]. Performing movements with a less mobile spine is associated with increased spine loading [7]. Tennis players with

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LBP have shown reduced ROM of the lower lumbar spine as well as a more laterally tilted pelvis than their asymptomatic counterparts [8]. Spinal kinematics may also be influenced by this type of physical exposure. Cross-sectional research has documented increased prevalence of rotation related deficits and spine movement asymmetries in individuals that participate in rotation related sports [9]. Furthermore, longitudinal research has shown decreases in spinal kinematic function in occupational work that involves more dynamic physical exposures [10], which may have implications for athletic populations that perform similar movements. However, while a relationship between participation in athletic activity and LBP has been identified, there is only limited research into movement patterns in people with LBP participating in these activities [11].

Dancers are required to perform many complex and repetitive movements of the spine, often to extreme ranges of motion, and therefore represent an ideal population to study spinal kinematics and LBP. Cohort studies have confirmed dancers experience LBP at least as much as, if not more than, general and sporting populations [12,13]. Research documenting high prevalence of spondylolysis in ballet dancers [14], as well as an association between dance hours and spinal stress fractures or LBP support a relationship between dance exposure and spine health [15,16]. Evidence also supports a unique spine profile in this population, with dancers presenting with flatter spine postures and greater sagittal plane spine mobility than non-dancers [17], as well as a prevalence of trunk asymmetries (measured with a scoliometer) and asymmetrical trunk muscle morphology [18,19].

Despite this, the relationship between dance, spinal kinematics, and LBP remains unclear. One previous kinematic study did not find an association between sagittal plane mobility and LBP in dance students [17], an observation which is counter to those from both athletic and non-athletic populations [2,4,8]. However, this study used a broad definition of dancer, considered only the sagittal plane, and modelled the lumbar and thoracic spine as single segments [17], which may be less able to provide accurate descriptions of spinal kinematics compared to a multi-segment model [20]. Elsewhere, unlike non-dance populations, measures including trunk stiffness and thickness of select paraspinal muscles did not discriminate between ballet dancers with or without LBP [18,21]. As such, kinematic differences should not be automatically assumed. Evaluating differences between dancers and non-dancers in simple measures of spinal kinematics that have previously been associated with LBP and that are common in clinical practice may provide insight into the interaction of dance, spine movement, and LBP. Therefore, the purpose of this study was to analyse spine posture, maximum ROM, and movement asymmetry in dancers and non-dancers with and without LBP.

2. Methods

2.1. Participants

Female professional and student dancers aged 15 years old and above, from both classical ballet and contemporary dance styles were recruited. Dance students were eligible for inclusion in this study if they were enrolled in senior level full-time training at a ballet school, a tertiary dance programme, or had recently (< 1 year) completed an equivalent programme. Dance professionals were eligible for this study if they were either dancing with a company or as an independent professional. Non-dancers were recruited to match the age and sex of the dancers. They were recruited from university and community settings. Dancers and non-dancers were allocated to the LBP group if they had experienced a minimum of two episodes of LBP in the past 12 months that resulted in activity modification, consultation with a health professional, or the use of medication. They were allocated to the Without-LBP group if they had not experienced any episode of LBP in the past 12 months. Exclusion criteria for all groups included known spinal deformities, pregnancy, or the presence of injury in any body region other than the lower back resulting in a modified training load or compromised spinal kinematics at the time of testing. Ethical approval was granted by the Australian Catholic University University Human Research Ethics Committee. All participants above the age of 18 (n = 50) provided written informed consent prior to participation in the project. Participants below the age of 18 (n = 10) provided informed parental/ guardian consent as well as participant assent.

2.2. Procedure and data collection

Prior to testing, participant height (cm) and body mass (kg) were collected using a stadiometer (SECA) and scales (A&D HW-PW200), respectively. For all participants, age (years), current and past medical history, as well as current and past LBP status were collected by questionnaire. Information on dance practice (e.g. current dance level, primary style, dance hours) and physical activity (e.g. moderate and vigorous activity type, weekly frequency, weekly hours) were collected for dancers and non-dancers, respectively using a standardised questionnaire. To obtain a more complete description of the LBP experience, participants with LBP indicated their current, typical, and worst pain intensity on a visual analogue pain scale and completed the Tampa Scale for Kinesiophobia (TSK) and Pain Catastrophizing Scale (PCS) [22,23].

Spinal kinematics were measured using a nine camera three dimensional Vicon Nexus motion analysis system (six MX13+ and three T20-S cameras, Nexus 2.2 software, Vicon, Oxford, UK) sampling at 100 Hz. A multi-segment spine marker set that has previously identified kinematic differences between individuals with and without LBP was used [24]. Seventeen (12 mm) reflective markers were attached to the pelvis, lumbar spine and thoracic spine of each participant, as previously described [24]. Five central markers were placed on the spinous processes of T1, T6, L1, L3 and L5, which were identified via palpation. Eight lateral markers were placed 5 cm either side from the midpoint of the central markers. Four markers were placed on the right and left posterior superior iliac spines and the anterior superior-iliac spines (Fig. 1).

After marker placement, trials of fundamental (normal) standing posture, frontal plane range of motion (ROM) in standing and transverse plane ROM in sitting were completed. For each task, a demonstration and standardised verbal instructions (Table 1) were provided to all participants. All tasks were performed in the same order, and at the participants own pace, to ensure that the most reliable measure of trunk motion was obtained [25,26]. Multiple practice attempts were provided, and two successful captures of each task were completed.

2.3. Data analyses

Gap filling was completed in the Vicon Nexus software and then the motion capture data was subsequently exported as C3D files. Kinematic parameters were quantified using Visual 3D (C-Motion, Inc. MD, USA) after marker data were filtered using a low-pass Butterworth filter at a cut-off frequency of 6 Hz to eliminate motion artefact. As described by Christe, Redhead [24], the trunk was divided into a series of five segments, including the pelvis (R + L ASIS, R + L PSIS), the lower lumbar segment (L3, L5, two midpoint markers), the upper lumbar segment (L1, L3, two midpoint markers), lower thoracic segment (T6, L1, two midpoint markers), upper thoracic segment (T1, T6, two midpoint markers). For each task, lower lumbar angles (LLa) were defined as the angles between the lower lumbar and pelvis segments, the upper lumbar angles (ULa) as the angles between the upper lumbar and lower lumbar segments, the lower thoracic angles (LTa) as the angles between the lower thoracic and upper lumbar segments and the upper thoracic angles (UTa) as the angles between the upper thoracic and lower thoracic segments. To calculate ROM in the movement tasks, the peak angles to the left were added to the peak angles to the right for each segment. To calculate asymmetry, the maximum absolute values to the

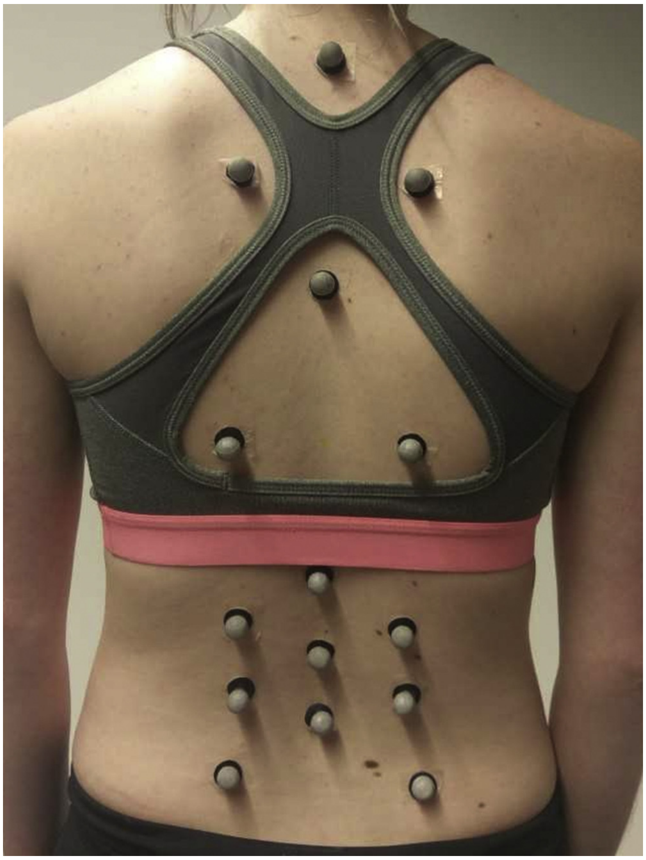

Fig. 1. Multi-segment spine marker set.

left were subtracted from the maximum absolute values to the right then divided by the total ROM and multiplied by 100 [26].

All statistical analyses were performed using SPSS software for Windows (version 22.0, SPSS Inc., IL, USA). Statistical significance was set at $p < 0.05$ for all tests. For demographic, pain intensity, TSK, and PCS variables, independent t-tests were used to examine for differences between dancers and non-dancers. For kinematic variables, the Shapiro-Wilk test was used to determine whether the data were normally distributed. Asymmetry variables for the LLa, ULa, and UTa in the frontal plane and LLa, LTa and UTa in the transverse plane were not normally distributed and thus log-transformed prior to any further analysis. Levene's Test was used to assess equality of variance. A two-way analysis of variance (ANOVA) was performed for each of the outcome variables to detect whether there were any differences between dancers and non-dancers, or individuals with and without LBP. Dance (two levels: dancer and non-dancer) and LBP (two levels: with LBP and without LBP) were entered as fixed factors. As the fixed factors were only two levels, no post-hoc tests were necessary. Partial eta squared (ηp^2) was obtained for all significant findings as a measure of effect size.

3. Results

Twenty-one female dancers (LBP n = 15) and 39 female non-dancers (LBP n = 18) volunteered to participate. Demographic data for all participants are presented in Table 2. There were no significant differences in age or height between dancers and non-dancers, but dancers had significantly lower body mass and BMI than non-dancers. For the participants with LBP, there were no differences in current, typical, or worst pain intensity. Nor were there differences kinesiophobia between dancers and non-dancers; however, dancers reported significantly higher PCS scores than non-dancers (Table 2).

For posture, there was a significant main effect for dance on the ULa ($F_{(1,56)} = 9.78$, $p < 0.01$, $\eta p^2 = 0.15$), with dancers demonstrating significantly smaller angles in the sagittal plane, suggesting a flatter standing posture. There was no main effect for LBP on posture for any segment. There was no interaction effect for dance and LBP on posture. For ROM, significant main effects of dance on ULa ($F_{(1,56)} = 4.49$, $p = 0.04$, $\eta p^2 = 0.08$) and LTa ($F_{(1,56)} = 5.09$, $p = 0.02$, $\eta p^2 = 0.09$) were observed in the frontal plane, with dancers achieving greater ROM compared to non-dancers. There was no main effect of dance on transverse plane ROM or any measure of movement asymmetry for any segment. There was also no main effect of LBP symptoms on ROM or movement asymmetry, nor was there any interaction between dance and LBP symptoms for these measures. Mean and significance values for standing posture, ROM, and movement asymmetry are presented in Table 3.

4. Discussion

The purpose of this study was to examine the relationship between dance, LBP, and multi-segment spinal kinematics. In our sample of female participants, dance had a significant relationship with fundamental posture and spine ROM for select segments and tasks. The dancers presented with a smaller upper lumbar angle when standing, indicating a flatter posture at this segment in the sagittal plane. In addition, dancers displayed significantly increased frontal plane ROM at the upper lumbar and lower thoracic segments compared to non-dancers. Dance explained between 8–15% of the variation observed in these measures. No relationship between LBP and spinal kinematics was observed, and no interaction between dance and LBP with spinal kinematics was observed.

Similar to previous research, there were differences in posture and ROM in dancers compared to non-dancers [17]. However, the total number of differences between dancers and non-dancers were small and these were limited to the upper lumbar and lower thoracic segments. Furthermore, although differences in frontal plane ROM were observed, there were no differences between dancers and non-dancers in transverse plane ROM. Therefore, the differences should collectively be viewed as modest, and, overall, measures such as posture and spine mobility appear to have limited ability to discriminate between trained dancers and non-dancers. With respect to asymmetry, previously, ballet students have exhibited a higher prevalence of trunk asymmetries measured with a scoliometer and ballet professionals have possessed asymmetrical trunk muscle morphology that is not evident in non-dancers [18,19]. Using three-dimensional motion capture and a multi-segment marker set, the current study did not observe any differences in

Table 1
Verbal instructions for movement assessments.

Trial	Verbal Instructions
Standing Posture	Stand relaxed how you would normally stand. Feet shoulder-width apart, knees straight and arms hanging freely, look forward.
Trunk Rotation	With your arms crossed over your chest (hands on shoulders) and keeping both sit bones on the stool, rotate your trunk to one side as far as you can, look over your shoulder, return to the starting position.
Side Bend	With your feet positioned pelvis width apart, easily bend to your (direction) side as far as you can, sliding your arm along your leg, return to the starting position.

Table 2
Participant descriptive data.

		Dancers (n = 21)	Non-Dancers (n = 39)	p
Demographics	Age (years)	21.5 (6.4)	22.9 (5.8)	0.42
	Height (cm)	165.6 (8.35)	165.2 (6.2)	0.85
	Body Mass (kg)	53.2 (7.5)	60.9 (8.6)	< 0.01*
	BMI	19.5 (2.7)	22.3 (2.8)	< 0.01*
Dance participation	Age started dancing	5.6 (2.5)		
	Dance experience (yrs)	14.9 (5.7)		
	Weekly dance hours	20.5 (9.8)		
Physical activity	Weekly MVPA hours		4.4 (3.3)	
LBP Information**	Current pain (/10)	2.1 (2.7)	0.9 (0.9)	0.15
	Typical pain (/10)	3.8 (1.6)	4.2 (2.2)	0.55
	Worst pain (/10)	6.7 (1.9)	6.6 (1.8)	0.68
	TSK (/52)	24.9 (5.7)	23.4 (5.7)	0.50
	PCS (/52)	17.1 (9.2)	8.9 (6.5)	0.01*

BMI = body mass index, MVPA = moderate to vigorous physical activity, *a statistically significant difference ($p < 0.05$), **LBP information provided for participants with LBP only (dancers n = 15, non-dancers n = 18).

movement asymmetry between dancers and non-dancers. While we did not measure muscle morphology, the implication of the current study is that these characteristics may not necessarily translate into more movement asymmetry than non-dancers.

The findings should also be considered in the context of previous studies examining physical activity types, spine posture, and movement patterns. Encouraging bipedal motion in animals precedes the development of a lordotic curve [27], which supports the notion that spine posture is influenced by activity type. Furthermore, participation in repetitive rotation related sports has been linked to specific movement adaptations that can be detected in clinical assessment [9]. However, while former elite gymnasts presented with a flatter thoracic posture than controls, there were no differences in spine mobility between gymnasts and non-gymnasts [28]. Similarly, in young dancers, gymnasts, and figure skaters, sagittal plane extension did not change as training progressed [28,29]. In the current study, select differences were observed between dancers and non-dancers, although the number of differences were small. This suggests that dance activity may just be one of the many contributors to habitual posture and spine mobility.

The present study did not find an association between spine posture, ROM, or movement asymmetry and LBP. Although non-neutral postures and reduced spine segment ROM have been associated with LBP [4,30], an absence of clear differences between groups with and without LBP is not without precedent [31]. In a three-year prospective study, reduced spine mobility was a significant predictor of more serious first time LBP, but it was not associated with transient LBP and only able to explain 2.1% of the variation in all the serious LBP experienced [2]. Previous results regarding movement asymmetry and LBP have been varied. Two kinematic studies that used similar movement tasks to the current study observed more asymmetrical spine movement in people with LBP [3,26]. In contrast, in clinical assessment, spine movement asymmetries were not associated with LBP unless the movement of a limb was involved [9]. Collectively, the relationship between LBP and movement does not appear simple or stereotypical [32]. In support of this, the present study suggests that generic interpretation of the simple clinical assessments used at a single time point may be of limited value for LBP in dance and non-dance populations.

There was no interaction effect for dance and LBP on spinal kinematics. Recent studies have shown that measures previously able to discriminate between people with and without LBP, such as trunk muscle cross-sectional area or spine stiffness, are less able to discriminate between dancers with and without a history of LBP [18,21] suggesting dancers may be resistant to changes often associated with LBP. However, the current study did not see an interaction between LBP

Table 3
Mean (SD) values and significance from the Two-Way ANOVAs.

	Angles	Dancer	Non-Dancer	p	With LBP	Without LBP	p	Interaction p
Standing Posture (degrees)	LLa	7.02 (8.15)	5.76 (10.34)	0.50	5.87 (10.32)	6.60 (8.77)	0.60	0.60
	ULa	7.40 (9.16)	14.26 (8.29)	< 0.01*	11.97 (9.05)	11.72 (9.42)	0.29	0.48
	LTa	1.23 (10.22)	−3.73 (6.46)	0.10	−0.33 (8.78)	−4.03 (7.17)	0.16	0.49
	UTa	−17.48 (6.43)	−19.18 (8.26)	0.27	−19.20 (7.37)	−17.84 (8.06)	0.30	0.59
Frontal Plane ROM (degrees)	LLa	16.10 (6.94)	16.74 (7.17)	0.69	16.45 (7.67)	16.59 (6.31)	0.69	0.72
	ULa	27.61 (10.20)	23.73 (6.24)	0.04*	25.42 (8.16)	24.72 (7.97)	0.53	0.15
	LTa	41.15 (9.50)	35.25 (7.35)	0.02*	38.66 (9.30)	35.69 (7.42)	0.52	0.85
	UTa	26.55 (6.02)	24.10 (5.89)	0.15	26.55 (5.55)	22.98 (6.07)	0.19	0.11
Frontal Plane Asymmetry [(R-L)/ (R + L)] x 100	LLa**	6.66 (2.48)	7.25 (2.40)	0.96	5.81 (2.64)	8.87 (2.03)	0.10	0.90
	ULa**	5.83 (2.55)	6.27 (2.27)	0.53	6.09 (2.55)	6.15 (2.14)	0.60	0.20
	LTa	6.30 (3.30)	8.00 (4.10)	0.28	6.78 (3.70)	8.19 (4.07)	0.21	0.47
	UTa**	4.87 (2.77)	7.49 (1.86)	0.09	5.95 (2.57)	7.13 (1.79)	0.65	0.96
Transverse Plane ROM (degrees)	LLa	9.55 (5.30)	9.31 (4.99)	0.51	9.41 (5.40)	9.37 (4.73)	0.45	0.13
	ULa	14.44 (4.06)	15.97 (5.00)	0.28	15.31 (4.37)	15.62 (5.19)	0.99	0.99
	LTa	35.41 (12.14)	33.73 (9.05)	0.75	35.67 (11.53)	32.68 (8.07)	0.34	0.93
	UTa	20.94 (10.87)	19.90 (8.79)	0.67	18.82 (7.42)	21.92 (11.31)	0.12	0.60
Transverse Plane Asymmetry [(R-L)/ (R + L)] x 100	LLa**	13.54 (2.88)	17.78 (1.97)	0.24	16.24 (2.27)	16.78 (2.32)	0.90	0.92
	ULa	16.12 (10.36)	14.37 (10.27)	0.54	13.70 (9.60)	16.50 (10.95)	0.45	0.37
	LTa**	6.46 (2.50)	6.02 (2.45)	0.74	5.74 (3.00)	6.66 (1.92)	0.62	0.72
	UTa**	10.23 (2.76)	13.49 (1.86)	0.27	11.83 (2.63)	12.57 (2.95)	0.78	0.47

* A statistically significant ($p < 0.05$) effect.

** Analysis performed on log transformed data. Mean and SD has been back transformed, LBP = Low back pain, LLa = Lower Lumbar, LTa = Lower Thoracic, ROM = Range of motion, ULa = Upper Lumbar, UTa = Upper Thoracic.

and spinal kinematics in non-dancers either. Thus, the present results cannot support the hypothesis that dancers are resistant to changes associated with LBP. Rather, despite the use of three-dimensional motion analysis, it is more likely that the simple posture, ROM, and movement asymmetry measures used were not sensitive enough to provide insight into movement changes associated with LBP. It is also important to acknowledge the development of LBP is often multifactorial in nature [1]. As such, adequate assessment of spine movement changes associated with LBP may require use of more probing kinematic assessment and functional or dance specific tasks, alongside possible subgrouping and appropriate biopsychosocial assessments.

Information on pain intensity, kinesiophobia, and pain catastrophising was collected to provide a more complete description of the LBP experience. No differences in current, typical, or worst pain intensity were observed between dancers and non-dancers with LBP, which suggests the current results were not influenced by fluctuations or severity of pain symptoms. Previous research that has identified altered spinal kinematics in LBP patients who were pain free at testing suggests that an absence of current pain does not impair the ability to identify kinematic deficits [24,33]. This also raises the issue as to whether kinematic assessment is sensitive to changes in pain symptoms, which is an area for future research. Dancers with LBP displayed increased pain catastrophising than non-dancers with LBP. Whether this suggests dancers either magnify the threat of pain or feel more helpless in its presence compared to non-dancers, which may be possible if they attribute their experience of LBP to their dance practice, also warrants further research.

Several methodological limitations should be considered when interpreting these findings. First, the cross-sectional nature of this study is unable to determine whether the small number of differences observed are caused by dance or merely reflect a selection bias within it. Second, this study was limited to a convenience sample of a well-trained, highly specialised population, for whom LBP is common [12,13], which limited the statistical power of the analysis and prevented subgrouping or adjustment for confounding. However, the 60 participants allowed a power of 0.86 to detect differences with a large effect between groups at an alpha level of 0.05, and, based on the observed effect sizes, a minimum sample of 368 participants would have been required to detect transverse plane ROM differences between dancers and non-dancers. Third, although there were no significant differences between participants for age, sex, and height, dancers had significantly lower body mass. Due to the traditional builds preferred in classical ballet, obtaining a control group matched for body mass was not achievable.

5. Conclusion

A small number of differences in spinal kinematics differentiated dancers from non-dancers. In this study, simple static posture, spine ROM, and movement asymmetry assessments often used in clinical assessment did not provide generalisable information on the experience of LBP symptoms in dance or non-dance populations.

Conflict of interest statement

The authors declare that they have no conflicts of interest relevant to the content of this study.

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