Effect of antenatal pilates on centre of pressure sway velocity and its correlation with the intensity of low back pain

Efecto del pilates prenatal sobre la velocidad de oscilación del centro de presión y su correlación con la intensidad del dolor lumbar

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Abstract

Introduction: Pilates have been shown to improve the postural control in previous studies. Also, the intensity of low back pain (LBP) may affect the postural control.
Objective: To determine the impact of antenatal Pilates on postural control of the pregnant females and whether the intensity of postural sway is correlated with the severity of LBP.
Methodology: A randomized controlled trial. The participants (18-35 years) were randomly allocated into two groups (31 in each group: Intervention group and Control group). The sway velocity of the centre of pressure was determined using a computerised balance evaluation system. The Visual Analogue Scale (VAS) was utilised to evaluate the severity of low back pain.
Results: A 2x2 mixed ANOVA showed significant results for average velocity of centre of pressure measured during eyes closed on hard surface ($F= 8.743$, $\eta p2 = 0.160$, $p = 0.005$), eyes open on foam surface ($F= 9.877$, $\eta p2 = 0.177$, $p = 0.003$) and eyes closed on foam surface ($F= 19.937$, $\eta p2 = 0.302$, $p = 0.001$) The posttest VAS scores weakly to moderately correlated in a positive manner, with the average velocity of postural sway during the third trimester.
Discussion: The static posture control of a pregnant woman is expected to deteriorate from second to third trimester. Pilates exercises enhances proprioceptive feedback and postural control by specifically targeting the core and pelvic floor muscles.
Conclusion: Pilates help pregnant women retain postural stability. This impact was greatest when the participants were tested on an unsteady surface without visual input. During the third trimester, LBP severity and postural sway depict weak to moderate positive correlation.

Keywords

Antenatal Exercises; Centre of Pressure; Low Back Pain; Maternal Health; Pilates; Postural Control.

Resumen

Introducción: Estudios previos han demostrado que Pilates mejora el control postural. Además, la intensidad del dolor lumbar (DL) puede afectar dicho control.
Objetivo: Determinar el impacto del Pilates prenatal en el control postural de las embarazadas y si la intensidad del balanceo postural se correlaciona con la gravedad del DL.
Metodología: Ensayo controlado aleatorizado. Las participantes (de 18 a 35 años) fueron asignadas aleatoriamente a dos grupos (31 en cada grupo: grupo de intervención y grupo control). La velocidad de balanceo del centro de presión se determinó mediante un sistema informático de evaluación del equilibrio. Se utilizó la Escala Visual Analógica (EVA) para evaluar la gravedad del dolor lumbar.
Resultados: Un ANOVA mixto 2x2 mostró resultados significativos para la velocidad promedio del centro de presión medida con los ojos cerrados sobre una superficie dura ($F = 8{,}743$, $\eta p2 = 0{,}160$, $p = 0{,}005$), con los ojos abiertos sobre una superficie de espuma ($F = 9{,}877$, $\eta p2 = 0{,}177$, $p = 0{,}003$) y con los ojos cerrados sobre una superficie de espuma ($F = 19{,}937$, $\eta p2 = 0{,}302$, $p = 0{,}001$). Las puntuaciones de la EVA posterior a la prueba mostraron una correlación positiva, de débil a moderada, con la velocidad promedio de balanceo postural durante el tercer trimestre.
Discusión: Se espera que el control postural estático de una mujer embarazada se deteriore del segundo al tercer trimestre. Los ejercicios de Pilates mejoran la retroalimentación propioceptiva y el control postural al trabajar específicamente los músculos del core y del suelo pélvico.
Conclusión: Pilates ayuda a las mujeres embarazadas a mantener la estabilidad postural. Este impacto fue mayor cuando los participantes fueron evaluados en una superficie inestable sin información visual. Durante el tercer trimestre, la gravedad del LBP y el desequilibrio postural muestran una correlación positiva débil a moderada.

Palabras clave

Ejercicios prenatales; Centro de Presión; Lumbalgia; Salud Materna; Pilates; Control postural.

Introduction

Women go through several endocrinal, anatomical and physiological transformations throughout pregnancy. Almost all the physiological systems undergo significant adaptive changes to facilitate foetal growth and prepare the mother and foetus for delivery (Tan & Tan, 2013). The majority of pregnant women have varying degrees of musculoskeletal discomfort, and around 25% report temporarily incapacitating symptoms (Borg-Stein et al., 2005). In addition to the discomfort and pain that accompany pregnancy, changes in the soft tissues, joints, and posture are significant because they affect postural balance and raise the risk of falling (Butler et al., 2006; Cakmak et al., 2016).

Compared to non-pregnant women, pregnant women are more prone to suffer injuries from falls. Falls during pregnancy can result in anything ranging from minor strains and sprains to complex and life threatening conditions like trauma to head, internal bleeding, uterine rupture or premature rupture of membranes which may even result in maternal or foetal death in some cases (Mirza et al., 2010). In an extensive study, the rate of falling during pregnancy was found out to be 26.8% (Dunning et al., 2010), while another study mentioned that 26.6% of the 2847 pregnant women who were employed reported falling at some point during their pregnancy, of which 6.3% happened in the working hours. The majority of the falls happened between six and seven months of pregnancy, and 66.3% happened when the woman was moving quickly, carrying something, or walking on a slippery surface (Dunning et al., 2003). There have been studies which have discovered that, after auto accidents, falls are the second most frequent source of trauma during pregnancy (El Kady et al., 2004; Kuo et al., 2007).

There are many extrinsic and intrinsic risk factors for falls during pregnancy. The main intrinsic risk factors are musculoskeletal and sensory changes that occur during that period, together with specific co-morbidities (Hrvatin & Rugelj, 2021). In addition to the physiological changes already discussed, laxity in the ligaments and joints, modifications to the spinal curvature, and weight gain, especially in the belly due to the growing foetus, all cause the body's centre of gravity to shift, ultimately resulting in postural instability. Arms and legs swelling, as well as decreased neuromuscular control and coordination, could also be considered as potential risk factors. Postural instability and the risk of falls during pregnancy are increased by certain conditions and lifestyle choices, including anxiety, hyperemesis gravidarum, gestational diabetes, and sedentary lifestyles (Cakmak et al., 2016; J. L. McCrory et al., 2010).

The evaluation of postural balance is vital during pregnancy since pregnant women have a tendency to lose balance, specifically during the later part of second trimester, third trimester and the postpartum period, which can lead to catastrophic issues for both the mother and the foetus. Many investigations evaluating postural balance during pregnancy have demonstrated increased postural instability, specifically higher antero-posterior sway (Butler et al., 2006; Danna-Dos-Santos et al., 2018; Davies et al., 2002; Jang et al., 2008). Exaggerated sway of the centre of pressure (COP) throughout the second and third trimesters compared with early pregnancy has been observed as a sign of altered balance ability (Oliveira et al., 2009). According to research, there is a greater chance of falling in the second and third trimesters than in the first, with the third trimester having the highest risk (Cakmak et al., 2014; Inanir et al., 2014).

Several approaches have been suggested to enhance balance, which in turn help to reduce the risk of falls both during and after pregnancy. Using maternity belts and engaging in physical activity or proprioceptive training can help improve postural stability and lower the risk of falls during pregnancy (Cakmak et al., 2014, 2016; El-shamy et al., 2019; J. McCrory et al., 2010; Roshko et al., 2024). Pilates, a low to no impact mind-body routine that focuses on breathing, core strength and concentration, is witnessing a rapid global receptiveness with widespread endorsement as a means of physical activity during pregnancy (Dillard, 2013; Perfeito et al., 2019). Pilates exercises have been shown to enhance postural balance and lower the likelihood of falls in different sets of studied populations (De Campos Júnior et al., 2024; Donatoni Da Silva et al., 2022; Lim et al., 2016; Pata et al., 2014; Walowska et al., 2018). Pilates workouts are safe and helpful during pregnancy. Any pregnant woman, without any contraindications, can safely use Pilates with proper adaptations without harming the foetus. Besides all the other advantages of exercises during pregnancy, Pilates seems to be especially beneficial for treating postural issues and creating a firm core with pelvic floor muscle activation (Malhotra et al., 2025). However, there is dearth of high-quality studies exploring the effect of Pilates exercises on postural balance control in pregnant women. Therefore, this study intends to find out the effect of Pilates based exercises on COP sway velocity in pregnant women.

As per research, low back pain (LBP) is one of the most common musculoskeletal problems during pregnancy, and it affects up to 90% pregnant women at some time. Postural changes coupled with production of hormone relaxin have been linked to this (Borg-Stein et al., 2005; Borg-Stein & Dugan, 2007; Gutke et al., 2008; Kinser et al., 2017; Oktaviani, 2018; Olsson & Lena, 2004; Perfeito et al., 2019; Pivarnik et al., 2006). There is paucity of literature on the relationship of LBP and postural control ability in pregnant women. Some of the studies suggest that postural stability or control are affected by LBP (Carvalho et al., 2020; Hrvatin et al., 2024; Öztürk et al., 2016), while the other authors suggest that there is no correlation between the two (Lira et al., 2019; Moreira et al., 2017). Considering the high prevalence of LBP during pregnancy, we also wanted to find out that whether there exists any correlation between the severity of LBP and postural control during pregnancy.

Method

Study Design and Setting

This is a randomized, parallel group, single blinded active controlled study. The therapist taking the dependent variable readings was blinded. The study followed the CONSORT guidelines for a randomised controlled trial. The participants were recruited from obstetrics and gynaecology outpatient department of Hakeem Abdul Hameed Centenary (HAHC) Hospital, Hamdard Institute of Medical Sciences and Research, Jamia Hamdard. After initial clearance by a gynaecologist for moderate intensity exercises, the participants were referred to the Sports and Exercise Science Research Laboratory, Department of Physiotherapy, Jamia Hamdard.

Approval from Ethics Committee

The institutional review board of Jamia Hamdard approved the study (reference no. JHIEC/04/2022, date of approval: 12/12/2022). Written informed consent was taken from all the participants. This study was executed in accordance with the Helsinki Principles and was included into the Indian Clinical Trials Registry using a trial identification number: CTRI/2023/02/049366.

Sample Size Calculation

The following equation was used for calculation of the sample size

For number of participants in each group (N) = 2σ2 (Z 1-α + Z 1-β)

______________ = 27

(μT - μ s -δ)2

S = Superiority Margin = 10%

μT - μ s = Expected Mean Difference = 21.2

σ = SD (14.2)

α = 5%

β = 90%

With 20% as dropout rate, we decided to recruit 32 participants in each group in the beginning. With β = 80%, number of participants required was 20 and with a 20% dropout rate, it came out to be 24 in each group.

Z is the standard normal distribution value

Expected mean difference – Difference between treatment group and standard treatment

Delta – Superiority margin

SD – Pooled standard deviation between treatment group and standard treatment group

Participants

Sixty-two pregnant women in their 20th to 25th week of pregnancy who were willing to come to the Department of Physiotherapy, for 2 days in a week for the supervised Pilates exercises were recruited for the study. The participants were between 18 to 35 years of age and had a pre-conception BMI between 18.5 to 24.9. The weight gain should have been within normal limits till 20th to 25th week of pregnancy. The participants were not taking part in any other physical activity program. Pregnant women were evaluated for any relative or absolute contraindications by a consulting gynaecologist and were given clearance for moderate intensity exercise participation. They were randomly allocated to the two groups using the chit system: PG = Pilates exercises group (Intervention Group); CG= Control group by an independent researcher. The CONSORT diagram of participant flow is available as figure 1. Pregnant women with multiple pregnancy (twins or more than two foetus), on hormone replacement therapy or on any other medication that can affect the exercise program were excluded. Pregnancy-related LBP was not an inclusion criterion owing to its high prevalence. Except for one participant, all research participants had low back discomfort when recruited. With 24 participants remaining in each group, finally the data of 48 participants was analysed.

Outcome Measures

Sway Velocity of the Centre of Pressure

The sway velocity of the COP was determined using the Humac balance system – HUMAC2015 system2 by Computer Sports Medicine, Inc. (USA). It contains a USB powered balance board with dimensions of 18x10.5x2.25 inches and a subject weight capacity of up to 150 kgs. The sway velocity of the COP can give information about how quickly a person sways in different directions in an attempt to maintain balance, potentially indicating changes in stability(Tipton et al., 2023). When comparing postural sway position, velocity, and acceleration data, the sensorimotor system favours information pertaining to velocity data (Jeka et al., 2004).

Intensity of Low Back Pain

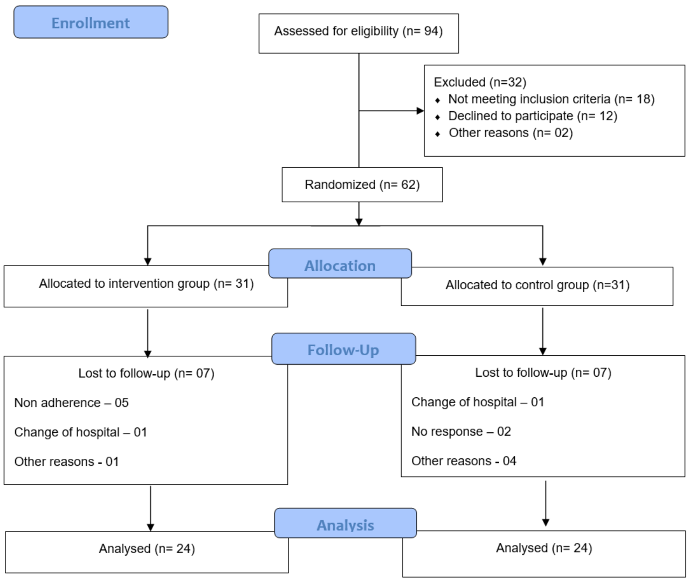
The Visual Analogue Scale (VAS) was used to assess the severity of LBP. It is a short and incredibly user-friendly tool for rating pain. The reliability and validity of the VAS have already been proven. Respondents record their subjective pain down a 10-cm line with adjectives at either end (ranging from none to severe) to complete the VAS assessment. The distance between the mark and the line's zero end is used to calculate the score. Pregnant women's pain levels have been assessed using VAS previously (Lira et al., 2019; Mirmolaei et al., 2017).

Interventions

Pilates Exercise Group

After allocation of participants to the Pilates group the subjects were given supervised Pilates program for eight weeks. Along with the standard protocol of care the subjects were made to do elastic resistance-based Pilates exercises twice weekly for eight weeks with a total of sixteen workouts. The Pilates exercise protocol included warm up for five minutes followed by main Pilates protocol for 25 to 30 minutes with 8-12 repetitions with proper form and technique for each exercise. Cool down for 5 minutes; slow stretches with each gentle stretch held for 15-20 seconds. Wall slides, leg slides, single knee drops, single knee or double knee folds, four-point kneeling, clam, bridge, reverse fly, resistance band rowing, leg circles, etc. were some of the Pilates exercises used with or without modifications as per the level of the participant. Elastic resistance band of appropriate intensity was used to incorporate additional resistance during the exercises. The Pilates exercises were given at the beginner's level to start with. Progression to intermediate and advanced levels was done only if the participant maintained proper form and technique of the progressed exercise, otherwise the previous level was maintained until the participant was able to do next level exercises properly. Progression of exercise was considered after two weeks of successful participation in the program.

Figure 1. CONSORT Flow Diagram



Control Group

Subjects followed the standard protocol of antenatal care followed at the Department of Obstetrics and Gynecology, HAHC Hospital (Hamdard Institute of Medical Sciences and Research, Jamia Hamdard). If required physiotherapeutic exercises were advised as home program with proper follow up for management of the back pain.

Procedure

The subjects already coming to the outpatient department of HAHC hospital for their antenatal visits were invited for participation in the study. All the necessary information, relative risk, and study benefits were imparted to all the participants. They were screened according to the pre-defined inclusion and exclusion criteria after they signed an informed consent form. Next, clearance was sought from the consulting gynaecologist for participation of the subjects in the Pilates exercise protocol. Further assessment, evaluation and data recording were done at the Department of Physiotherapy.

The baseline measurements of Sway Velocity of the COP and pain ratings using the VAS scale were taken for all the participants. The participants were first familiarised with the Humac balance system and were explained the procedure of testing and what is expected from them. The testing on the Humac balance system was conducted in four phases, each one of 30 seconds. First two phases were done by the subjects with standing directly on the balance board (Hard surface – HS) and the subsequent two phases were done by the subjects standing on a foam surface (Foam - FS), placed on the balance board.

At the beginning, the anatomical landmarks of the feet were aligned according to the markings on the balance board and the subjects were asked to stand on the balance board as per the instructions given to them. The first phase was of 30 seconds, in which the subjects were asked to maintain their balance on the hard surface in double limb stance with visual feedback – "eyes open hard surface" (EOHS), in second phase the visual feedback was removed by closing the eyes – "eyes closed hard surface" (ECHS). After that a foam piece, supplied along with the Humac balance system was placed on the balance board, and the subjects performed the third and the fourth phases. The same double limb stance was used, with visual feedback in the third – "eyes open foam surface" (EOFS) and without visual feedback in the fourth – "eyes closed foam surface" (ECFS). No subject lost her balance during the testing procedure and a therapist was standing behind the participant during the testing procedure as a precautionary measure. In front there was a hand railing to hold on to in case the subject loses balance.

After the balance assessment the women were asked to rate the severity of their LBP on VAS. They were asked to make a mark on a 10 cm line corresponding to the severity of their pain. They were explained that the left end of the line corresponds to no pain and the right end corresponds to unbearable pain with the severity of pain increasing from left to right direction. The distance between the mark and the line's zero end was used to calculate the score.

After the baseline measurements, the participants were randomly allocated to the intervention group or the control group. In the intervention group, supervised Pilates exercises, as described above, were administered in addition to the routine antenatal care. The control group followed the standard antenatal care protocol of the HAHC Hospital. Posttest measurements of the dependent variables for both the groups were taken after the completion of the eight weeks period.

Data analysis

The IBM SPSS software version 26 was utilised to conduct the statistical analysis. The descriptives were evaluated and the normality of the data set was tested using the skewness and kurtosis statistics and also the Shapiro-Wilk test. Tests were performed (t tests or χ2 tests) to test for differences between the two groups. For inferential statistics, a 2 x 2 mixed design repeated measures analysis of variance was used to elicit an interaction between the time and group. Partial Eta squared (ηp2) values gave an idea about the effect size of the intervention on the average velocity of COP under all four testing conditions. Paired T test was used for evaluating the differences between the pretest and posttest readings for all four components of balance testing conditions. Pearson's coefficient of correlation was used to study the correlation between the pretest VAS scores and the pretest scores of average velocities of COP, posttest VAS scores and the posttest scores of average velocities of COP, combined pretest, posttest VAS scores and the combined pretest, posttest scores of average velocities of COP under all four conditions respectively. The statistical results were considered significant for $p < 0.05$.

Results

The demographic characteristics of the participants in the intervention and control group are summarised in table 1.

A 2x2 mixed ANOVA showed significant interaction of time and group for average sway velocity of COP measured during eyes closed on hard surface (F= 8.743, ηp2 = 0.160, p = 0.005), eyes open on foam surface (F= 9.877, ηp2 = 0.177, p = 0.003) and eyes closed on foam surface (F= 19.937, ηp2 = 0.302, p < 0.001). Whereas no significant difference was shown for eyes open on hard surface (F = 0.910, ηp2 = 0.019, p = 0.345) among intervention and control group for pretest and posttest readings. The results of the mixed ANOVA for time and group interaction and the effect sizes are presented in table 2. The interaction graphs of time and intervention for pretest and posttest readings for the average sway velocity scores of all four balance testing conditions are represented in figure 2 (a-d).

Table 1. Demographic Characteristics of the Participants.

	Control Group (n= 24) Mean ± SD	Intervention Group (n=24) Mean ± SD	p value
Age (years)	26.37 ± 3.50	26.25 ± 4.41	0.914
Weight (Kgs) - Pre	56.71 ± 8.13	57.17 ± 7.13	0.836
Weight (Kgs) - Post	60.83 ± 8.37	61.42 ± 6.92	0.794
Height (cms)	157.93 ± 7.12	156.44 ± 4.35	0.387
BMI (Pre)	22.67 ± 2.30	23.35 ± 2.65	0.348
VAS (Pre)	38.63 ± 19.85	51.25 ± 25.36	0.061
VAS (Post)	36.00 ± 14.77	23.21 ± 18.82	0.012*
Gestation Weeks (Pre)	22.50 ± 1.89	22.38 ± 1.6	0.818
Gestation Weeks (Post)	32.13 ± 1.90	32.21 ± 1.96	0.881
Gravida			
1	11 (45.8%)	11(45.8%)	0.478
2	8 (33.3 %)	4 (16.7%)	
3	4 (16.7%)	7 (29.2%)	
4	1 (4.2%)	2 (8.3%)	
Parity			
0	13 (54.2%)	13 (54.2%)	0.390
1	9 (37.5%)	6 (25%)	
2	2 (8.3%)	5 (20.8%)	
Abortions			
0	18 (75%)	17 (70.8%)	0.598

1	6 (25%)	6 (25%)
2	0	1 (4.2%)

VAS: Visual Analogue Scale; BMI: Body Mass Index
*Significant at 0.05 level.

The pairwise comparison for the control group demonstrated that there was a statistically significant difference between the pretest and posttest readings of sway velocity in ECHS (t= -3.507, p = 0.002), EOFS (t= -4.55, p = < 0.001) and ECFS (t= -5.407, p = < 0.001) testing conditions. The rest of the comparisons for the control group and the intervention group did not reveal any statistically significant differences. The pretest and posttest readings of sway velocity for both the groups are summarised in table 2 along with the inferential statistics of T test. The bar charts showing the mean scores of sway velocity at different time points for the control and Intervention groups are depicted in figure 3 and figure 4 respectively.

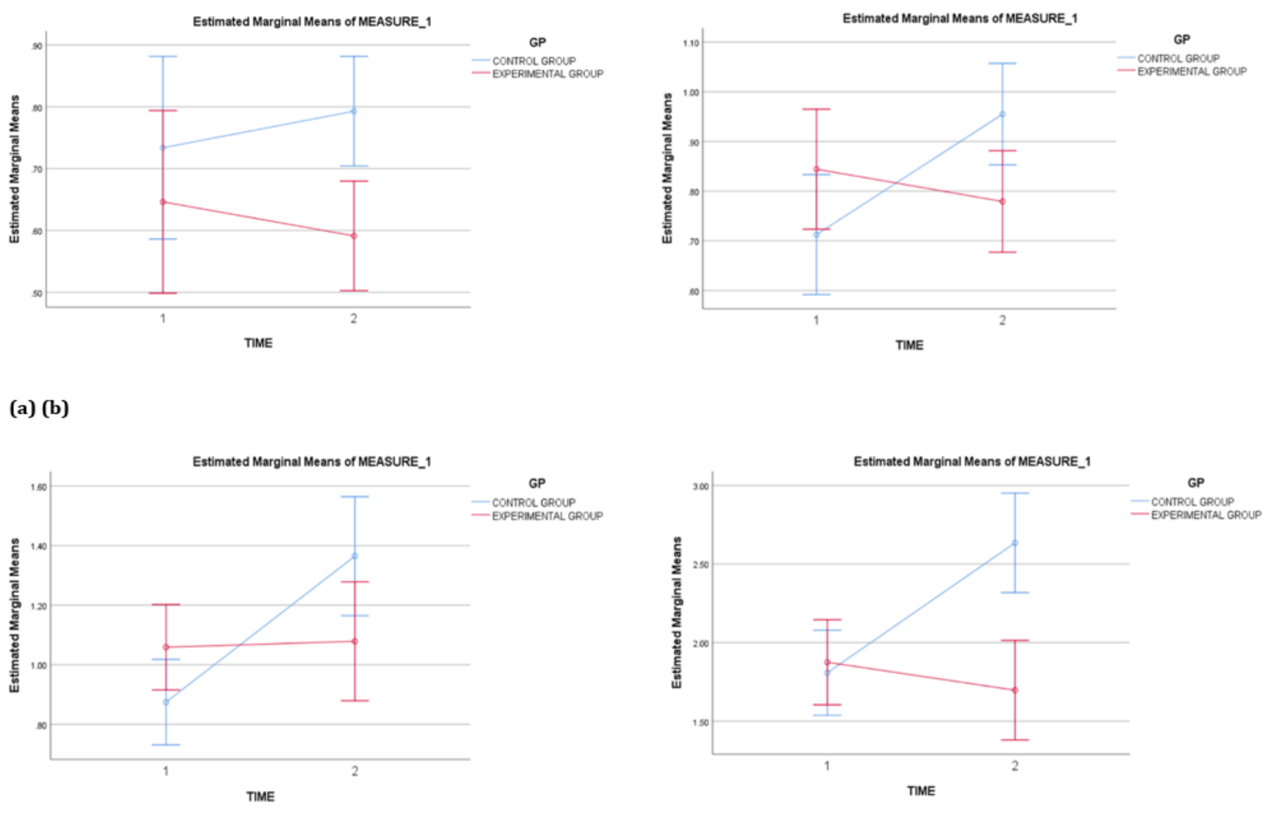
Table 2. Descriptive and Inferential Statistics (2 x 2 mixed ANOVA) for Interaction Between Time & Group and Comparison of Pretest and Posttest Readings of Sway Velocity Scores of COP Under Four Testing Conditions.

AV of COP Testing Condition	Group	AV of COP Pretest Scores Mean ± SD	AV of COP Posttest Scores Mean ± SD	F Value	Sig.	Partial Eta Squared ηp^2	t Value	Sig.	Effect Size d
EOHS	Control Gp.	0.73 ± 0.46	0.79 ± 0.27	0.910	0.345	0.019	-0.546	0.590	0.16
	Int. Gp.	0.65 ± 0.22	0.59 ± 0.15				1.082	0.290	0.32
ECHS	Control Gp.	0.71 ± 0.20	0.96 ± 0.29	8.743	0.005*	0.160	-3.507	0.002*	1.00
	Int. Gp.	0.84 ± 0.36	0.78 ± 0.20				0.837	0.411	0.21
EOFS	Control Gp.	0.87 ± 0.23	1.36 ± 0.55	9.877	0.003*	0.177	-4.55	< 0.001*	1.16
	Int. Gp.	1.06 ± 0.44	1.08 ± 0.41				-0.193	0.849	0.05
ECFS	Control Gp.	1.81 ± 0.60	2.63 ± 0.91	19.937	< 0.001*	0.302	-5.407	< 0.001*	1.06
	Int. Gp.	1.87 ± 0.71	1.70 ± 0.61				1.076	0.293	0.26

EOHS: Eyes Open Hard Surface; ECHS: Eyes Closed Hard Surface; EOFS: Eyes Open Foam Surface; ECFS: Eyes Closed Foam Surface; AV: Average Velocity; COP: Centre of Pressure; Int. Gp: Intervention Group; * Significant at 0.05 level.

The initial group wise correlation analysis of control group revealed a statistically significant moderate negative correlation between the pretest VAS score and the pretest score of sway velocity under ECFS condition (r = -0.418, p = 0.042), moderate positive correlation between the posttest VAS score and the posttest score of sway velocity under ECHS condition (r = 0.490, p = 0.015). For experimental group, a statistically significant moderate positive correlation was observed between the posttest VAS score and the sway velocity score under the EOFS (r = 0.483, p = 0.017) and the ECFS (r = 0.537, p = 0.007) conditions respectively. A statistically significant positive correlation was found between the combined posttest VAS scores of the two groups and the combined (two groups considered as one) posttest scores of sway velocity under all four testing conditions. With r = 0.302 and p value 0.037, the sway velocity values under EOHS, ECHS (r = 0.392, p = 0.006) and ECFS (r = 0.384, p = 0.007) conditions showed weak positive correlation, while under EOFS (r = 0.435, p = 0.002) showed moderate positive correlation (Schober et al., 2018). The combined pretest VAS scores of the two groups did not show significant correlation with the combined pretest group scores of sway velocity under any of the four testing conditions. The Pearson correlation coefficient values for all the combinations of correlation are mentioned in table 3.

Figura 2.



(a) (b)

(c) (d)

Interaction Graphs of Time and Intervention for Average Sway Velocity of Centre of Pressure Measured During Four Testing Conditions (a) Eyes Open Hard Surface, (b) Eyes Closed Hard Surface, (c) Eyes Open Foam Surface, (d) Eyes Closed Foam Surface; 1 = Pretest; 2 = Posttest.

Discussion

This study investigated the effect of Pilates exercises on postural control in pregnant females specifically during second to third trimester. To begin with, there was no statistical difference between the demographic characteristics of the participants in two groups. We observed a statistically significant difference between the two groups in the readings of the sway velocity of COP between the two time points for all testing conditions except the EOHS one. It signifies that when the within group factor (pretest vs posttest) and the between group factor (control group vs intervention group) were considered for an interaction, the results of both the groups were different at two time points.

On further analysis of pair wise comparison within the groups, it was found out that there was a statistically significant difference between the pretest and posttest readings of sway velocity of COP under ECHS, EOFS and ECFS testing conditions for the control group only. For the intervention group there were no statistically significant differences in the pretest and posttest readings of sway velocities of COP under any of the four testing conditions. COP velocity is a sensitive variable for investigating changes in postural sway and has been widely used to reflect postural stability. An increase in postural sway velocity will signify a poor postural control (Beaupré et al., 2022; Beserra Da Silva et al., 2010; Burke et al., 2010; Greig et al., 2007; Jeka et al., 2004; Tipton et al., 2023). It was observed that the average sway velocity of the COP increased in the control group only, as the participants progressed from second trimester to the third trimester. There was no significant increase in the EOHS testing condition (from 0.73 + 0.46 to 0.79 + 0.27 cm/s). Out of ECHS, EOFS and ECFS the maximum increase (1.81 + 0.60 to 2.63 + 0.91 cm/s) was seen in ECFS testing condition and the least significant increase was seen in ECHS condition (0.71 + 0.20 to 0.96 + 0.29 cm/s).

Table 3. Correlation Statistics Between Intensity of Low Back Pain and Sway Velocity of COP for Both the Groups Separately and Both Groups Combined at Two Time Points

VAS	Sway Velocity of COP Testing Condition – (Both Group Combined) (n=48)	r-value	Sig.
Time Point 1 Combined Pretest Scores (n=48)	PRE EOHS	0.055	0.712
	PRE ECHS	-0.055	0.710
	PRE EOFS	-0.084	0.572
	PRE ECFS	-0.091	0.538
Time Point 2 Combined Posttest Scores (n=48)	POST EOHS	0.302	0.037*
	POST ECHS	0.392	0.006*
	POST EOFS	0.435	0.002*
	POST ECFS	0.384	0.007*
VAS (PRE) (n=24) Control Group	PRE EOHS	0.168	0.431
	PRE ECHS	-0.181	0.398
	PRE EOFS	-0.274	0.194
	PRE ECFS	-0.418	0.042*
VAS (POST) (n=24) Control Group	POST EOHS	0.207	0.332
	POST ECHS	0.490	0.015*
	POST EOFS	0.293	0.165
	POST ECFS	0.017	0.939
VAS (PRE) (n=24) Int. Group	PRE EOHS	-0.003	0.988
	PRE ECHS	-0.100	0.641
	PRE EOFS	-0.125	0.562
	PRE ECFS	0.095	0.658
VAS (POST) (n=24) Int. Group	POST EOHS	0.165	0.441
	POST ECHS	0.129	0.548
	POST EOFS	0.483	0.017*
	POST ECFS	0.537	0.007*

VAS: Visual Analogue Scale; EOHS: Eyes Open Hard Surface; ECHS: Eyes Closed Hard Surface; EOFS: Eyes Open Foam Surface; ECFS: Eyes Closed Foam Surface; COP: Centre of Pressure; Int. - Intervention
*Significant at 0.05 level.

Figure 3. Pretest and Posttest Mean Values of Sway Velocity of Centre of Pressure for the Control Group

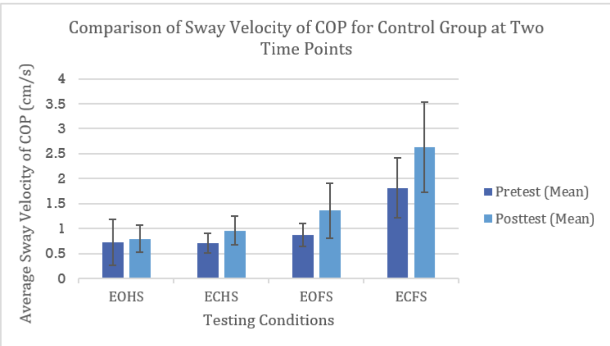
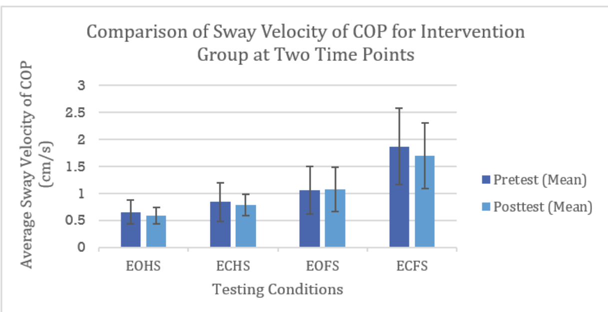


Figure 4. Pretest and Posttest Mean Values of Sway Velocity of Centre of Pressure for the Intervention Group



The absolute weight increase is more till the third trimester as compared to the weight gain till the second trimester and the centre of mass of the body is shifted anteriorly (Wu & Yeoh, 2014). The expanded abdominal volume may cause the rectus and transverse abdominal muscles' fibres to distend, which, when combined with alterations in pelvic angulation, may lead to paravertebral extensor musculature overload and discomfort (Cordeiro et al., 2018; Oktaviani, 2018). Compared to those that occur in the third trimester of pregnancy, musculoskeletal alterations that typically occur throughout pregnancy progression are less apparent in the second trimester (Cakmak et al., 2016; Segal & Chu, 2015). The second trimester of pregnancy has lower levels of the hormone relaxin than the third (Goldsmith & Weiss, 2009). Obesity also has an impact on static stability in general population. It is linked to posturokinetic deficiencies and a higher risk of falling (Inanir et al., 2014). According to Corbeil et al., obese people may be more likely to fall than light people, especially if they have an irregular distribution of body fat in the abdomen region (Corbeil et al., 2001). The same response can be expected in pregnant ladies in our study with excessive weight distribution in the abdominal area. There was a mean increase of 4.1kgs and 4.3kgs of weight in the control group and experimental group participants respectively.

A study by Hrvatin et. al. demonstrated that, the postural control is maximally affected during the third trimester regardless of the pelvic girdle pain (Hrvatin et al., 2024). Other studies have shown that pregnancy has a major impact on third-trimester static stability (Butler et al., 2006; J. L. McCrory et al., 2010; Oliveira et al., 2009), as well as during the second trimester (Butler et al., 2006; Inanir et al., 2014; J. L. McCrory et al., 2010). In addition, third-trimester pregnant women had higher sway area, COP excursion velocity, and struggled keeping a steady standing posture than second-trimester pregnant women (Butler et al., 2006; Inanir et al., 2014; J. L. McCrory et al., 2010; Oliveira et al., 2009). As shown by earlier research, a pregnant woman's static posture control is likely to deteriorate from second to third trimester due to all the changes that occur during this transition. We also got similar results as previous studies, as there was a decrease in postural control in three of the four testing conditions for the control group participants. The postural control of the subjects in the intervention group did not deteriorate. This change may be attributed to the Pilates exercises given to this group. Evidence suggests that Pilates exercises enhance postural control by specifically targeting the core and pelvic floor muscles (De Campos Júnior et al., 2024; Donatoni Da Silva et al., 2022; Lim et al., 2016; Pata et al., 2014; Walowska et al., 2018).

Pilates is based on the premise that exercises may be added to test the stability of the core once it has been developed. This concept has several advantages during pregnancy. Improvements in the mother's core stability would have a positive impact on the COP's sway velocity. Pilates greatly improves breathing, posture, and back pain while also promoting mental and physical well-being (Balogh, 2005; Kaya et al., 2012; La Touche et al., 2008; Olsson & Lena, 2004). Previous studies also suggest that Pilates during pregnancy either maintains (Bulguroğlu et al., 2023), or improves postural stability (Bulguroğlu et al., 2023; Hyun & Jeon, 2020; Martin C et al., 2017). General physical activity has also been shown to improve balance and postural stability in pregnant women (Roshko et al., 2024).

Explanation for a maximum increase of sway velocity in the ECFS testing condition would be that the visual feedback is not there and also an element of instability in the form of foam surface has been incorporated. We already know that for static stability, pregnant women heavily rely on visual feedback (Butler et al., 2006; Conder et al., 2019; Inanir et al., 2014; Nagai et al., 2009; Opala-Berdzik A. et al., 2014) as a result of compromised proprioceptive perceptions (Nagai et al., 2009; Ratnani et al., 2023; Wakkar & Patil, 2022).

With the initial group wise correlation analysis, we got mixed results with depiction of both negative and positive correlations between the respective VAS scores and the average sway velocity scores. Previous literature indicates that we get more reliable correlation results with larger sample sizes (Schönbrodt & Perugini, 2013). In order to have a correlation result with a relatively larger sample size, we ran a correlation analysis between the respective combined VAS scores and the combined sway velocity scores under four testing conditions of both the groups. A weak to moderate positive correlation was observed between the combined posttest VAS scores of the two groups and the combined posttest readings of sway velocity of COP under all four testing conditions of both the groups. No correlation was observed for the corresponding pretest scores. Jinhan et. al. in their meta-analysis concluded that increased postural sway is linked to chronic LBP, and the biggest effect sizes are seen when visual feedback is removed in presence of higher self-reported pain intensity (Park et al., 2023). Previous studies show that patients with LBP have an increased postural sway, particularly under restricted vision and complex tasks (Hamaoui et al., 2011; Mientjes & Frank, 1999; Öztürk et al., 2016). Improper proprioceptive inputs of the central nervous system in patients with chronic LBP may contribute to postural imbalance (Chung et al., 2013; Hamaoui et al., 2011; Mientjes & Frank, 1999; Öztürk et al., 2016). Thus, this relationship is in agreement with those of the previous studies. But we need to consider these results with caution, since the correlation was observed for the pottest scores only. Out of the total 48 subjects in consideration, half of the subjects had recently concluded Pilates training and half of them were in control group. The possible reason for not getting a correlation for the pretest scores could be that LBP may have different effect on postural balance in the second trimester. Also, with increased load in the third trimester and more strain on the back stabilising musculature, the LBP may show significant relationship with the postural deficits. This needs to be explored further. Therfore, we recommend that future research studies with large sample sizes shall try to address this hypothesis. We did not set a threshold for the low back pain intensity for inclusion in the study. As the pregnancy related LBP is highly prevalent, we could factor in a wide range of low back pain intensities for the correlation study.

The small sample size was one of our study's limitations. The same study protocol could be performed in a larger population. We measured only static stability of the participants. All primigravida women could have been included in the sample. There could be an additional third group also of age, BMI and sway velocity matched controls. To evaluate the impact of LBP on postural stability, particularly across all three trimesters of pregnancy, additional studies must be conducted. Further evaluation of the impact of Pilates activities on postural stability under both static and dynamic conditions requires large, longitudinal, high-quality studies with the presence of normal controls.

Conclusions

Pilates training during pregnancy can help to maintain the postural control of the pregnant females during the later part of pregnancy. This effect was most pronounced when the testing was done with the subject standing on foam surface with eyes closed, signifying the importance of Pilates training in improving the proprioceptive feedback and core stability. We expect that the response of training in standing balance variables will irradiate to the dynamic balance also. However, future studies would be required to validate that. Due to its low impact nature, it appears to be one of the best types of exercise that may be recommended during pregnancy, both individually and in group settings for improvement in postural stability. However, further high-quality randomised controlled studies are necessary to support our conviction that this approach should be used throughout pregnancy.

Also, there seems to be a mild to moderate correlation between the intensity of LBP and the extent of postural sway in pregnant females during the third trimester. Addressing the low back pain in pregnant females may help in improving the postural control, which in turn may potentially reduce the incidence of falls in the pregnant population, decreasing both the morbidity and mortality related to falls during pregnancy. Considering the beneficial exercises of exercise during pregnancy, it needs to be more widely prescribed to pregnant ladies, specifically in a developing country like India.

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