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Comparative analysis of the effects of real-time audio-visual feedback, yoga and pressure biofeedback stabilizer in core strengthening: a randomised controlled trial

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Abstract

Study aim: To compare the efficiency of a pressure biofeedback stabilizer (PBS), Riablo audio-visual feedback (RAV), and yoga in core strengthening exercise protocols in overweight individuals with trunk instability.
Materials and methods: The randomized controlled trial included 144 overweight individuals with trunk stability $\leq$ 42.3% (72 male, 72 female), age 27 ± 5 years and BMI 27.1 ± 1.1. They were equally divided into three experimental groups (PBS, RAV, and Yoga) and one control group. A pre-test was conducted for trunk instability using the modified double straight leg lowering test followed by 6 weeks of core strengthening exercise protocols. A post-test was conducted four times after commencing the exercise protocols at the end of the first, second, third and sixth week.
Results: The RAV group exhibited significant improvement from the first week (β = 1.5, SE = 0.33, p = 0.02) to the sixth week (β = 20.2, SE = 0.329, $p < 0.001$) in trunk stability. Although the first week result was negligible for the Yoga group, it showed improvement from the second week and reached a maximum at the sixth week (β = 13.9, SE = 0.329, $p < 0.001$). The PBS group showed slow but consistent improvement, noted from the third week and reaching a peak in the sixth week (β = 6.9, SE = 0.329, $p < 0.001$), while the control group exhibited no progress in trunk stability.
Conclusions: The RAV training protocol improved core stability in overweight subjects faster than yoga and PBS protocols. All three training protocols improved core stability and balance compared to the control group, and exhibited a time-dependent association. To attain trunk stability faster and more efficiently, we suggest implementing the RAV core strengthening protocol.

Keywords: Core Stability – Low back pain – Postural Balance – Sensory Feedback – Yoga

Introduction

Low back pain (LBP) is recognized as a global health concern, with the World Health Organization reporting that approximately 619 million individuals were affected by LBP in 2020, a figure projected to rise to an estimated 843 million by 2050 (GBD, 2023). Major risk factors for LBP encompass obesity, smoking, psychological distress, and poor general health (Heliövaara, 1989; Shiri et al., 2019). Obesity stands out as a modifiable risk factor for low back pain (Heliövaara, 1989; Heliövaara et al., 1991). Assessing obesity can be effectively achieved through two primary indicators of body composition: the body mass index (BMI) and the waist-hip ratio (Vadasova et al., 2016). BMI is negatively correlated with trunk stability, characterized by a lack of core muscle strength and control, which can significantly impair an individual's ability to perform daily activities and participate in physical exercises. The core can be described as a muscular box with the abdominals at the front, paraspinals and gluteals at the back, the diaphragm as the roof, and the pelvic floor and hip girdle musculature as the bottom (Akuthota et al., 2008; Lee et al., 2023). The core is the "powerhouse", the foundation or engine of all limb movements, and plays a major role in providing spinal stability (Akuthota et al., 2008). The spine stability system consists of the following interacting elements: neuromuscular control (neural elements), passive subsystem (osseous and ligamentous elements) and active

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subsystem (muscular elements) (Arjmand & Shirazi-Adl, 2006; Hodges et al., 2013; Reeves et al., 2019).

Functional stability and movement are critically dependent on the coordination of all the muscles surrounding the lumbar spine (Akuthota et al., 2008). Although many researchers advocate the importance of the transversus abdominis (TrA) and multifidus, co-contraction of all the core muscles plays a vital role in optimal stabilization and performance. To acquire this co-contraction, precise neural input and output are prerequisites (Reeves et al., 2019). Any disruption to this complex process may lead to functional trunk instability.

Untreated functional trunk instability may lead to chronic low back pain and structural damage to the spinal structure (Fernández-Rodríguez et al., 2022; Hodges et al., 2013). Trunk instability is a prevalent condition with significant functional limitations, necessitating the exploration of interventions that can enhance stability (Fernández-Rodríguez et al., 2022; Hodges et al., 2013; Reeves et al., 2019). Despite core strengthening exercises being commonly recommended, there is only limited research in comparing the effectiveness of different modes of strengthening programmes. Our interests focus on the recent advancement in rehabilitation using technologies to augment core strengthening and enhance the understanding of motor learning in core strengthening.

Feedback and cues in motor learning: Motor learning can be understood as the creation of an internal model that depicts the precise correspondence between perceived sensory and motor information (Krakauer et al., 2019; Schmidt & Wrisberg, 2008; Spampinato & Celnik, 2021). Early motor learning is characterized by unskilled, highly feedback-dependent movements that place a heavy attention load on the learner (Blum, 2008; Smyth & Wing, 2013). Practice increases action velocity and accuracy while decreasing the significance of feedback processing (Dye et al., 2009; Krause et al., 2018). Early on in the motor learning process, subjects will learn the correct movements by trial and error with the help of a provided sensorimotor translation map. The ability to translate sensory inputs into motor output requires working memory retention (Boettcher et al., 2021; Van Ede et al., 2019). Action execution will be still sluggish and unskilled, fully dependent on attention processing and feedback. Sensorimotor maps strengthen and are retained in long-term memory with practice (Baugh et al., 2016). Visual cues translate quickly and precisely into the appropriate motor response. As a result, action can be carried out faster now with less intensive sensory feedback processing (Alamia et al., 2019). Long-term practice makes movements automatic, enabling subjects to perform tasks quickly and accurately even when they are not paying attention to them.

Riablo's audio-visual feedback (RAV) protocol using Riablo's virtual platform has been designed to provide real-time feedback applying concepts of motor learning. A pressure biofeedback stabilizer (PBS) uses sensory feedback to reinforce the core muscle activity at the early stages of core strengthening. Yoga is a well-accepted concept of flexibility and strength training exercise that coordinates one's body with the mind, and most of its exercises involve core muscle activation. By using all these concepts discussed so far, our study intended to compare the efficiency of a PBS, Riablo's virtual platform, and yoga in a core strengthening exercise protocol applied in overweight individuals (BMI 25 to 30) with trunk instability. We hypothesized that the efficiency of improving trunk stability would vary with different exercise protocols.

Materials and methods

Trial design: A double-blinded randomized controlled design was used to test the hypothesis. A total of 144 (72 male and 72 female) subjects were randomly selected from a pool of 200 eligible participants using an Excel sheet and included in this study (Fig. 1). Those subjects (N = 144) were randomly assigned to three experimental groups – RAV (n = 36), Yoga (n = 36), PBS (n = 36) – and one control group (n = 36) using the same software. This study was approved by the institutional review board of Gulf Medical University (UAE) with reference number IRB-COHS-FAC-23-SEPT-2023 and was conducted according to the ethical guidelines of the Declaration of Helsinki 1964 and Declaration of Tokyo 1975. It was performed transparently and presented in accordance with CONSORT guidelines. The study was carried out and data collected in Thumbay Physical Therapy and Rehabilitation Hospital (TPTRH), UAE. Participants were recruited from Thumbay University Hospital and TPTRH, UAE. Physiotherapists and post-graduate students at the department evaluated the participants for participating in the study according to the eligibility criteria. Participants: All the participants were informed about the research design, experimental protocols, outcome measures, benefits and harms through a study information form. To take part in the study, subjects signed informed consent approved by the ethical committee and were allowed to withdraw from the study at any point in time without any conditions. Inclusion criteria for selection of subjects were as follows: overweight subjects (BMI 25 to 29.9) aged between 18 to 40 years with trunk instability (MDSLL test range ≥ 65°). Exclusion criteria were individuals with severe cardiovascular or respiratory conditions that limited their ability to participate in physical exercise; history of hip pathology, spinal cord injury and neurological disorders affecting trunk stability; surgical procedures and fractures related to the trunk or core muscles; and female subjects who had undergone intrauterine conception and caesarean section. We excluded 13 participants whose MDSLL control was below 65°, 2 participants who had undergone lumbar surgery, 6 who were undergoing fitness training, 2 with a history of caesarean section and 4 not willing to participate.

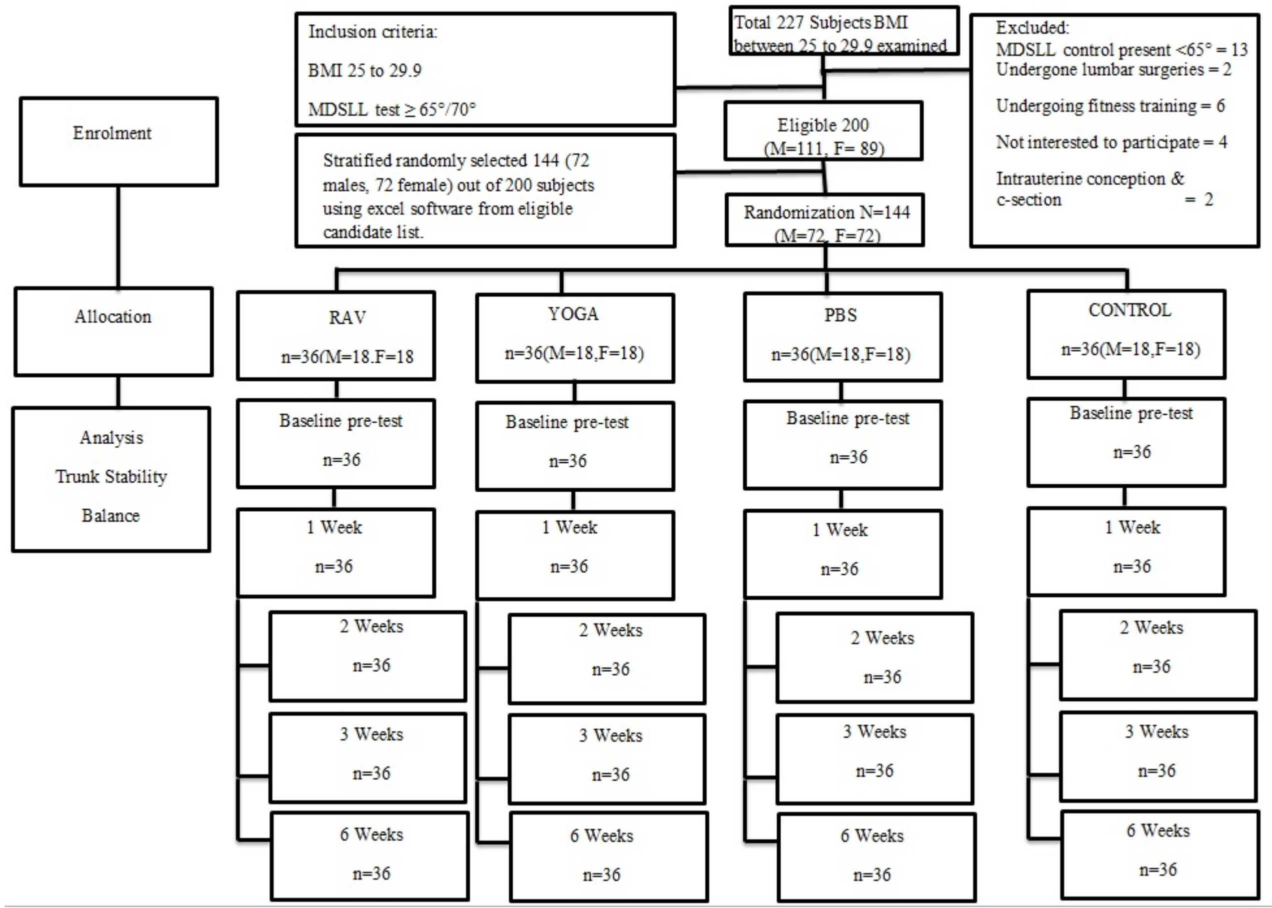

Figure 1. Flowchart showing the study details

Training programme and protocols: RAV, Yoga and PBS groups underwent a 6-week core strengthening exercise protocol approved by the institutional review board. The exercise protocol was administered by eight well-trained licensed physiotherapists (three with more than ten years of experience and the rest with more than three years of experience), six post-graduation students and two certified yoga instructors. These exercise protocols were designed to improve the trunk stability by improving motor control and core muscle strength augmented by different types of feedback.

Riablo AV group: The RAV protocol (Table 1) was administered by three physiotherapists and two post-graduate students using three Riablo machines in the TPTRH high performance laboratory. For every single session the training protocol described below was followed. The preparation for each training session involved fitting the inertial measurement units (IMU) to the body with the straps as guided by the machine (Riablo system-CoRehab, Trento, Italy). The machine calibrated the IMUs, pressure platform and body alignment before starting each training session. Each exercise started with a virtual task of flying an object through targets to reach the destination (Fig. 2). The task was designed like running on a track, starting at the zero-metre mark and ending at the hundred-metre finishing line. The flying object progresses on the track only if the subject performs the desired body angle as prompted by the software. The software in turn provided three different types of feedback in the monitor accordingly to how accurately the targets were achieved. The types of feedback were: i) numerical scores in percentage; ii) change of target colour to green for correct and red for incorrect; iii) two distinct sound effects for right and wrong actions. The training time per session took approximately 20 minutes; the system provided five seconds of rest in between each exercise. The subjects underwent four training sessions each week for six consecutive weeks with a change in protocol after the first three weeks, as described in Table 1.

Yoga group: The yoga training session took place in an indoor stadium on the Gulf Medical University premises in four batches as group therapy for male and female participants separately for the first three weeks. It was conducted by two certified yoga instructors and two post-graduate students. The yoga protocol (Table 1) involved supervised performance of exercises by the subjects in guidance of the yoga instructors for the first three weeks and following the same at home for the next three weeks with printed exercise pamphlets. Each single session was approximately 20 minutes with five minutes of warm-up and cool-down. The subjects performed yoga four times a week for a total of six weeks.

Table 1. Core strengthening training protocols

RAV training protocol	Yoga training protocol	PBS training protocol
FIRST PHASE (first 3 weeks, 4 days per week) 1. Pelvic bridging static 10 s × 5 reps × 2 sets 2. Lying hip flexion static (right & left) 10 s × 5 reps 3. Lying hip abduction static (right & left) 10 s × 5 reps 4. Lying hip extension static (right & left) 10 s × 5 reps 5. Standing hip flexion static (right & left) 10 s × 5 reps 6. Standing hip abduction static (right & left) 10 s × 5 reps 7. Standing hip extension static (right & left) 10 s × 5 reps 8. Single limb standing with opposite hip and knee bent static (right & left) 10 s × 5 reps 9. Single limb standing with opposite shoulder flexion static (right & left) 10 s × 5 reps 10. Pelvic bridging on Swiss ball static 10 s × 5 reps × 2 sets	**Same protocol for 6 weeks (4 days per week).** 1. Tadasana (Palm Tree Pose) – 10 s × 5 reps 2. Tiryaka Tadasana (Swaying Palm Tree Pose) – 10 reps 3. Marjaryasana-Bitilasana – 10 reps 4. Dandayamana Bharmanasana – 10 s × 5 reps 5. Yogamudrasana (Psychic Union Pose) – 10 s × 3 reps 6. Matsyasana (Fish Pose) – 10 s × 3 reps 7. Utkatasana – 10 s × 5 reps 8. Lolasana (Swinging Pose) – 10 s × 3 reps 9. Bhujangasana (Cobra Pose) – 10 s × 3 reps 10. Sarpasana (Snake Pose) – 10 s × 5 reps 11. Dhanurasana (Bow Pose) – 10 s × 5 reps 12. Ardha Chandrasana (Half Moon Pose) – 10 s × 3 reps 13. Setu Asana (Bridge Pose) – 10 s × 5 reps 14. Garudasana - 10 s × 3 reps 15. Navasana – 10 s × 3 reps 16. Ashta Chandrasana - 10 s × 3 reps 17. Vasisthasana – 10 s × 3 reps	**FIRST PHASE (first 3 weeks, 4 days per week)** 1. Abdominal drawing in prone lying with Chattanooga pressure biofeedback stabilizer (CPBS) and hold it for 10 seconds × 4 repetitions 2. Crook lying with CPBS abdominal drawing in hold 10 s × 4 reps 3. Knee outs 10 reps × 4 sets 4. In same position maintaining the pressure at 40 mmHg raise one arm overhead followed by the other 10 s × 10 reps × 4 sets 5. Crook lying with both arms overhead 10 reps × 4 sets 6. Crook lying raise one leg 10 reps × 4 sets 7. Crook lying opposite arm raise with opposite leg 10 reps × 4 sets 8. Crook lying with both arms raise with one leg raise 10 reps × 4 sets 9. Supine lying both arms overhead raise 10 reps × 4 sets 10. Supine lying with heel slides 10 reps × 4 sets 11. Bridging (along with abdominal draw combined with multifidus contraction) 10 s × 10 reps x 4 sets 12. Bridging with alternate heel raise 10 reps × 4 sets 13. Bridging with knee lift (one knee at a time) 10 reps × 4 sets 14. Bridging one knee extended 10 reps × 4 sets 15. Bridging one knee extended and flexed back to original position 10 reps × 4 sets.
SECOND PHASE (4–6 weeks, 4 days per week) 1. Pelvic bridging with leg extension (right & left) 15 reps × 1set 2. Pelvic bridging on Swiss ball dynamic 15 reps × 1 set 3. Sitting side flexion in chair 15 reps × 1 set 4. Standing trunk flexion dynamic 10 reps × 1 set 5. Standing heel raise toe touch 10 reps × 1 set		**SECOND PHASE (4–6 weeks, 4 days per week)** 1. Quadrapod position 10 reps × 4 sets 2. Quadrapod with one hand raise - don't spill the water from the cup in the hand 10 reps × 4 sets 3. Quadrapod with opposite hand and opposite leg 10 reps × 4 sets 4. Quadrapod with rocking backward and forward 10 reps × 4 sets 5. Quadrapod with single leg lift and lowering 10 reps × 4 sets

RAV training protocol	Yoga training protocol	PBS training protocol
6. Plank 8 reps × 1 set 7. Hip flexion on plank 10 reps × 1 set 8. Dog kick 15 reps × 1 set 9. Romanian dead lift 10 reps × 1 set 10. V-sit Abs 8 reps × 1set		6. Diagonal leg lifts with hand 10 reps × 4 sets 7. Bridging on Swiss ball 10 reps × 4 sets 8. Side bridging on knees 10 reps × 4 sets 9. Side bridging with upper limb movements 10 reps × 4 sets 10. Side bridging on legs with upper limb and lower limb movement 10 reps × 4 sets 11. Prone arm and leg lift 10 reps × 4 sets 12. Kneeling with one arm lift 10 reps × 4 sets 13. Kneeling with both arms lift 10 reps × 4 sets 14. Kneeling to gradual bending down in front followed by bending back 10 reps × 4 sets 15. Kneeling with gradual bending in front and back with both arms raised 10 reps × 4 sets 16. Half kneels to gradual lowering in front 10 reps × 4 sets

PBS group: PBS protocols (Table 1) were administered by five physiotherapist and two post-graduate students. The first phase took place in TPTRH, and the second phase was taught with printed material; participants were instructed to follow it at home and were reminded to perform the exercise. The PBS protocol involved the use of a pressure biofeedback Stabilizer unit (Stabilizer, Chattanooga Group Inc., Hixson, TN, USA) to activate the core muscles in the first phase of training (Table 1). The subjects underwent six weeks of training involving two different phases of exercises four times a week, adapted from Sharma et al. (2012).

The control group was not assigned any exercises; they were taught core strengthening exercises at the end of research completion. Following the pre-test, the experimental group underwent a structured core strengthening exercise protocol designed accordingly for six weeks. Post-tests for trunk stability were conducted following one, two, three and six weeks for all four groups; the post-test of balance was conducted once after six weeks (Fig. 1).

Outcome variable testing protocols:

Modified double straight leg lowering (MDSLL) test: Trunk stability was measured using the MDSLL test. For the MDSLL test, participants underwent a pre-test session involving instruction and practice of the abdominal hollowing manoeuvre (Sharma et al., 2012; Shimizu et al., 2019). During the test, subjects were instructed to lie supine with a pillow under their knees. They were instructed to perform pelvic bridging, and the Chattanooga pressure biofeedback Stabilizer (Stabilizer, Chattanooga Group Inc., Hixson, TN, USA) was placed under the lumbar area. It was inflated to 60 mmHg, and the subjects were then told to modify the pressure to 40 mmHg by performing abdominal hollowing and adjusting their spinal muscles. Once this had been learnt, the inflated Stabilizer unit was removed without deflation, and an electronic goniometer (Lafayette Instrument Co, Lafayette, IN) was attached to the right thigh and calibrated to zero at ground level. Next, both of the participant's legs were lifted to 70 degrees by the first examiner and the Stabilizer unit was reinserted before commencing the test. At 70 degree of leg raise, the participants were asked to achieve 40 mmHg, which they had learnt earlier by contracting and adjusting their spinal musculature. After that, their legs were left by the first examiner and they were told to lower the legs toward the ground without a change in pressure of ± 10 mmHg. If any changes ± 10 mmHg occurred, the corresponding goniometer degree was recorded and the test was stopped by the second examiner. That degree was incorporated in the trigonometry formula and cosineθ of that number was identified and multiplied by 100 to find the numerical percentage of the performed MDSLL test. In our preliminary study (15 subjects), we determined that test-retest

Figure 2. Riablo's exercise platform – Subject performs pelvic bridging with leg extension

reliability for the MDSLL test was high, based on an intra-class correlation coefficient of 0.97 (95% CI: 0.94–0.99)

Total stability index (TSI): The subjects were made to stand on a Bluetooth connected bipodalic board in front of a digital wall (D-Wall Elite Technobody, Dalmine BG, Italy) and TSI was tested. The subjects were instructed to balance on the bipodalic board for one minute as guided by the software. Before starting the test, one practice session was conducted for adaptation of subjects to the new system. Following the test, the software analysed TSI and the results were generated.

Limits of stability (LOS): The subjects were requested to stand on the strength plate in front of the D-Wall and LOS was tested. The software directed the user to achieve new points on the system by voluntarily displacing their centre of gravity between the base of support through new varied visual prompts. Once the test was concluded, the system provided the LOS results by analysing trunk sway and time taken to achieve the task.

Sample size: The required sample size for the study was calculated using G*Power (Version 3.1.9.7) for a one-way analysis of variance (ANOVA) with four groups. We aimed to achieve a power of 0.80 with a significance level of α = 0.05. The effect size was set at 0.29, reflecting a moderate difference between the groups in previous studies. The total sample size for all four groups was set to 136 participants, which corresponds to 34 participants per group. To account for a 5% expected drop-out rate, a total sample size of 144 participants was determined.

Randomization was performed using a person who was not involved in the data collection process. Using Excel, the selected 144 participants were randomized and allocated to four groups, ensuring an unbiased group allocation for subsequent analysis.

Blinding: Due to the design of the study, it was not possible for us to blind the therapist involved in training the group. The subject and therapist assessing the outcomes at baseline, after 1 week, 2 weeks, 3 weeks and 6 weeks were blinded. Hence, the assessing therapist was always blind to the subject's allocated treatment group, and the treating and assessing therapists were two different persons. The assessing therapists were given three special training sessions to make them understand and master the measurement of outcome variables to avoid individual variations. Subjects were instructed not to share the study procedures and exercise protocol with other subjects and the assessing therapist.

Statistical analysis: To analyse the effects of the RAV, Yoga, PBS and control groups, both within and between groups over repeated time measurements, a linear mixed model (LMM) was used for trunk stability and balance. The model included groups as the fixed effect to compare the outcome across groups. Time was modelled as a repeated measures factor with measurements recorded at baseline, one week, two weeks, three weeks, and six weeks after commencing exercises to assess trunk stability changes over time. The group × time interaction was examined to determine whether the treatment effects varied across the different time points in accordance with groups. Random intercepts for participants were included to account for individual variability and the correlation of repeated measurements within subjects. For balance assessment, which was measured only at baseline and after six weeks of intervention, LMM was used to compare the effects of the four groups at these two time points. All statistical analyses were performed using SPSS software (ver. 29.0.2.0), with the significance level set at 0.05.

Results

Our 144 subjects were randomly and equally allocated to three experimental groups and one control group. The intention-to-treat analysis method was used in this study, but all the participants completed the study with no drop-out. Table 2 provides demographic data including age, height, weight and BMI of all four groups.

Table 2. Demographic data of the population

Variables	RAV	Yoga	PBS	Control
Age	25.9 ± 4.7	27 ± 4.6	26 ± 4.4	27 ± 5.1
Height	166.7 ± 4.3	165.5 ± 4.2	167.4 ± 3.4	166.2 ± 4
Weight	75.7 ± 5.9	74.7 ± 4.8	76.9 ± 3.4	75.9 ± 4.8
BMI	27.1 ± 1.1	27.2 ± 1.1	27.1 ± 1.1	27.3 ± 1.1

RAV – Riablo's Audio Visual Group, PBS – Pressure Biofeedback Group, BMI – Body Mass Index

Table 3 shows the mean±SD comparison of descriptive statistics computed for the dependent variable MDSLL, LOS and TSI across the four groups at each time point in weeks. The data revealed variability in the MDSLL, LOS and TSI scores across groups and time points, with notable differences observed in experimental groups compared to the control group at each time point.

The fixed effects results revealed a significant group by time interaction, indicating that the effect of experimental groups on trunk stability and balance differed over time. Table 4 summarizes the mean difference, 95% confidence intervals (CI), upper and lower bound values within groups and significance between groups over time.

Table 3. Descriptive data of the dependent variables

Group	RAV	Yoga	PBS	Control
MDSLL baseline	38.9 ± 1.9	38.4 ± 1.8	39.4 ± 2	38.6 ± 2
MDSLL post 1	40.5 ± 1.7	38.8 ± 1.9	39.7 ± 1.9	38.7 ± 2
MDSLL post 2	47 ± 1.9	42.4 ± 1.9	40.1 ± 2.2	38.8 ± 2.1
MDSLL post 3	51.7 ± 1.6	45.9 ± 1.9	42.4 ± 2	38.8 ± 1.7
MDSLL post 6	59.5 ± 2.1	52.6 ± 2	46.6 ± 2.3	38.9 ± 1.9
LOS baseline	78 ± 3.7	77 ± 3.7	77 ± 3.8	76 ± 3.8
LOS post 6	84 ± 3.4	83 ± 3.9	79 ± 3.7	76 ± 3.8
TSI baseline	4.9 ± 0.7	5 ± 0.5	5.2 ± 0.7	4.9 ± 0.6
TSI post 6	4.1 ± 0.7	4.2 ± 0.5	4.9 ± 0.7	4.9 ± 0.6

RAV- Riablo's Audio Visual Group, PBS – Pressure Biofeedback Group, MDSLL – Modified Double straight Leg Lowering test, TSI – Total Stability Index, LOS – Limits of Stability. post -test timeline in weeks.

Table 4. Mean difference and group by time interactions

Group / **Weeks**	**RAV** Mean difference, 95% CI(lower,upper)	**Yoga** Mean difference, 95% CI(lower,upper)	**PBS** Mean difference, 95% CI (lower,upper)	**Control** Mean difference
MDSLL **Post 1**	1.51[(0.2,2.7) p = .02]	0.27(–1,1.5)	0.27(–1,1.5)	0.1
MDSLL **Post 2**	7.91*(6.6,9.1)	3.85*(2.6,5.1)	0.58(–0.7,1.8)	0.2
MDSLL **Post 3**	12.63*(11.3,13.9)	7.33*(6.1,8.6)	2.87*(1.6,4.1)	0.2
MDSLL **Post 6**	20.22*(18.9,21.4)	13.85*(12.6,15.1)	6.94*(5.7,8.2)	0.3
LOS post 6	5.87*(3.4,8.3)	5.86*(3.4,8.2)	2.63*(0.2,5.1)	0
TSI post 6	–0.74*(–1.1,-0.34)	–0.79*(–1.2,-0.39)	–0.29[(–0.7,0.1) p = 0.03]	0

* $p < 0.001$, RAV – Riablo's Audio Visual Group, PBS – Pressure Biofeedback Group, MDSLL – Modified Double straight Leg Lowering test, TSI – Total Stability Index, LOS – Limits of Stability.

The graph (Fig. 3) shows that significant improvements were found in all experimental groups at different time points. As shown in Table 4, the RAV group exhibited substantial increases in the MDSLL test from week 1 to week 6, and the β coefficient increased from 1.51 (SE = 0.33) to 20.22 (SE = 0.33), with p-values being highly significant ($p < 0.001$). The effects of the Yoga group became more pronounced starting from week 2 and showed a progressive improvement in the MDSLL test until week 6. The effect was most prominent at 6 weeks, when the β coefficient was 13.86 (SE = 0.33), showing a significant change from baseline to post-intervention ($p < 0.001$). The PBS group started to show a significant difference from week 3 and continued until week 6. The PBS group showed a more moderate but still significant effect, at 6 weeks, $\beta = 6.94$ (SE = 0.33, $p < 0.001$) indicating continued improvement over time. The balance parameter (LOS and TSI) results shows that RAV [(LOS, $\beta = 5.87$, SE = 1.24, $p < 0.001$), (TSI, $\beta = -0.74$, SE = 0.20, $p < 0.001$)] and Yoga [(LOS, $\beta = 5.86$, SE = 1.24, $p < 0.001$), (TSI, $\beta = -0.79$, SE = 0.20, $p < 0.001$)] groups improved significantly more than PBS and control groups, although PBS (LOS, $\beta = 2.64$, SE = 1.24, $p = 0.03$) showed significantly greater improvement than the control group in LOS and no significant difference in TSI. There was no significant difference in improvement between RAV and Yoga groups in balance performances.

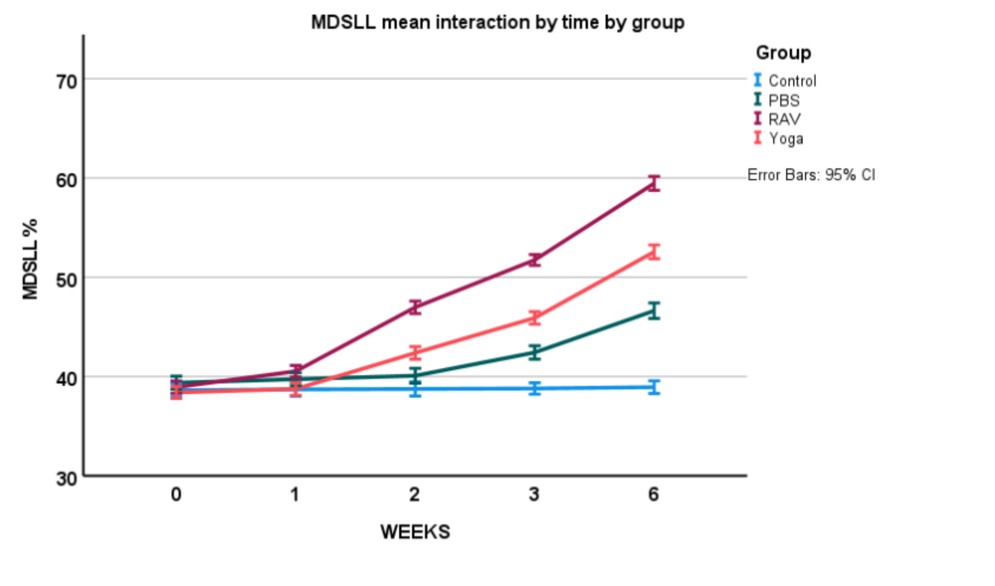

Figure 3. Trunk stability graph. X-axis represents timeline in weeks, Y-axis represents MDSLL %

Discussion

Trunk instability and core strengthening exercise programmes: The results suggest that the core strengthening exercise programme improves trunk stability compared to no exercise. The level of improvement varies with different exercise protocols, especially with respect to the emphasis on sensory feedback.

Riablo audio-visual training group and trunk stability: The RAV regime was designed to focus on activating the core muscles in the first phase with isometric exercises and the second phase to focus on dynamically incorporating it with activities. The results show that the RAV group started to improve in trunk stability in the first week (β = 1.513), when the other groups did not show any significant change. The RAV group maintained its improvement until the end of 6 weeks, reaching the highest stability (β = 20.218) compared to the other groups. The RAV group may have achieved better results because it mainly focused on precise incorporation of desired body angle with visual and auditory feedback in various exercises using the CoRehab platform. In line with our findings, various studies conducted with same principles of motor learning involving video games and virtual reality in orthopaedic rehabilitation have improved muscle strength and balance (Donath et al., 2016; Lee et al., 2017; Sun & Chen, 2020). Lee (2013) found that training using video games effectively improved muscle strength and tone in chronic stroke patients. Nambi et al. (2020) reported that a virtual reality (VR) training group improved significantly more in functional performances in sports than an isokinetic training group. They posited that the improvement was due to VR training increasing the sensory activity of the brain, which in turn increased the motor activity by providing real-time feedback to complete the task and created the desire to be promoted to the next level in the games. The games in VR training activate the experience related to brain plasticity through the changing environments. The gaming exercises which we used in Riablo also worked in the same state of altering game environments and challenging situations by providing specific tasks involving core muscle activity. Studies conducted with the help of EMG reported that specific postures increased core muscle activity the most maximum, e.g. the plank, downward dog pose, squat (Shimizu et al., 2019; Zazulak & Medvecky, 2019). When a subject performs the same activity without any feedback due to fatigue, they may not achieve the desired level of effort to produce maximum efficiency in every repetition. But when we incorporate audio-visual feedback within controlled times and angles, it helps the subject to maintain the desired position in exercise and produce efficient results. RAV involves all three components of core stability with AV augmentation, which may have been responsible for the better results observed in our study.

Yoga group and trunk stability: The results show that the Yoga group improved trunk stability from the second week of starting the exercise programme, and it produced better results compared to the PBS and control groups. Our protocol was composed of static, dynamic and functional poses, which demanded the maximum use of core muscle to perform the exercises. Poses such as Lolasana, Navasana and Vasisthasana mainly focused on improving trunk flexor strength. Dandayamana Bharmanasana, Matsyasana, Sarpasana, Dhanurasana and setu asana were used in extensor strengthening. Utkatasna, Ardha Chandrasana, Garudasana and Astha chandrasana helped in improving core muscle strength by demanding isometric contraction of core muscles and other postural muscles to produce these poses. Neha and McAuley found that regular yoga practice is as effective as stretching and strengthening exercises in their study (Gothe & McAuley, 2016). Park et al. (2015) found that yoga improved isokinetic trunk strength, in line with our finding that yoga improved trunk strength and stability. Cowen and Adams (2005) found that 6 weeks of astanga yoga improved trunk dynamic muscular strength, endurance and flexibility, reinforcing our finding that the 6-week yoga protocol improved trunk stability.

Pressure biofeedback stabilizer group and trunk stability: The results show that the PBS group started to exhibit significant improvement from the third week onwards and stability improved more towards six weeks. It showed marked improvement when compared to the control group but not superior to RAV and yoga. This may be due to the less demanding nature of the protocol compared to the other groups. The PBS group improved in trunk stability at a slow pace first by isolation training of the TrA and multifidi. This protocol may be more useful for early stages in acute LBP patients, but other protocols may be more useful in subjects with no pain but engaged in improving trunk stability. Park (2021) found that the PBS unit was more effective in improving lumbo-pelvic control, which is in line with our study on recruiting core muscles. Sharma et al. (2012) found that PBS was effective in improving trunk stability in comparison with the control group, corroborating our finding of improvement in the PBS group.

Core strengthening and balance: The results show that both the balance parameters LOS and TSI improved in the strengthening groups compared to the control group. There was no difference in balance improvements between RAV and Yoga groups, but they remained superior when compared to PBS. The protocols used in both RAV and yoga incorporated functional activities in core strengthening, which could be the major reason for this improvement. Studies have obtained similar results in improvement of static balance by core strengthening in players with trunk instability (Belli et al., 2022; Haruyama et al., 2017; Sannicandro, 2017; Sharma et al., 2012). Virtual-reality training can stimulate the cerebral cortex and enhance patients' spatial orientation capacity, thus facilitating the cortical regulation of balance and improving motor function (Mao et al., 2015; Sehrt et al., 2023).

Limitation: We included only overweight subjects with trunk instability, so we are unable to extrapolate the effects of the same protocols to elite athletes.

Conclusion

Riablo's audio-visual training protocol improved core stability in overweight subjects faster than yoga and PBS protocols. All three training protocols improved core stability and balance when compared to the control group. Our research findings indicate that the exercise protocols have time-dependent effects on trunk stability, with the RAV group achieving the most substantial and sustained benefits. We recommend implementing RAV training protocols to attain trunk stability faster. We also recommend future research in implementing the RAV training protocol for players with trunk instability.

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