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Impact of Blood Flow Restriction Resistance Training on Mobility, Balance, and Stability in Middle-Aged Adults

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Abstract

This study investigates the effectiveness of Blood Flow Restriction (BFR) resistance training in enhancing mobility, balance, and stability in middle-aged adults, key factors for maintaining independence and reducing fall risk. A total of 48 participants (mean age 55.72 ± 1.85 years; mean height 1.74 ± 0.06 m; mean weight 73.47 ± 8.18 kg) were randomly assigned to either a BFR training group or a control group. The BFR group completed a 12-week low-intensity resistance training program, while the control group followed a traditional exercise routine. Functional Movement Screen (FMS) tests assessed mobility, balance, and stability before and after the intervention. Results revealed significant improvements in the BFR group for balance (mean increase: +1.33, $p < 0.001$), stability (+1.08, $p < 0.001$), and lower body mobility, particularly in the Active Straight Leg Raise (ASLR) test (+0.38, $p < 0.05$). Minimal changes were observed in the control group. These improvements align with enhanced neuromuscular activation, proprioception, and core strength induced by the hypoxic environment of BFR training. The findings highlight BFR training as a practical, low-intensity intervention for addressing age-related functional declines. It offers an accessible alternative for individuals unable to perform high-intensity resistance training, with potential applications in fall prevention, rehabilitation, and functional health optimization. Future research should examine its long-term effects and broader applicability across diverse populations.

Keywords: Functional Movement, Neuromuscular Adaptation, Fall Prevention, Proprioception.

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Introduction

The gradual decline in physical function, including mobility, balance, and stability, begins to manifest during middle age and can significantly compromise independence and quality of life. This decline stems from physiological changes such as reduced muscle mass, flexibility, and proprioceptive abilities, as well as diminished neuromuscular coordination (Moreno et al., 2019). These functional components are foundational to daily activities and play a critical role in reducing the risk of falls, which are a leading cause of injury and disability among middle-aged and older adults (National Institute on Aging, n.d.; World Health Organization, 2021; Srivastava & Muhammad, 2022). Despite their importance, interventions specifically targeting these functional domains remain limited, particularly in addressing age-related physical decline.

Resistance training is widely regarded as an effective strategy to maintain and improve physical function in middle-aged individuals. Studies have demonstrated that resistance training enhances muscle strength, bone density, and joint health, thereby mitigating the effects of sarcopenia and osteoporosis (Alajlouni et al., 2023; Massini et al., 2022; Cheng et al., 2024). However, traditional resistance training often necessitates high-intensity exercise to achieve these benefits, which may be unsuitable for middle-aged individuals with joint discomfort, chronic conditions, or limited access to facilities. These limitations underscore the need for alternative approaches that provide comparable outcomes with reduced physical strain.

Blood Flow Restriction (BFR) training has emerged as a promising alternative. This innovative technique involves applying external pressure to restrict venous blood flow while maintaining arterial inflow, creating a hypoxic environment in the working muscles. This condition enhances metabolic stress and muscle activation, allowing significant physiological adaptations even at low-intensity loads (Cognetti et al., 2022; Saraf et al., 2022). Research has shown that BFR training effectively promotes muscle hypertrophy and strength gains comparable to high-intensity resistance training, with the added advantage of minimizing joint stress and physical strain (Chang et al., 2024; Mirzayev & Levitt, 2024; Geng et al., 2024).

Although the effects of BFR training on muscle hypertrophy and strength are well-documented, its impact on functional parameters such as mobility, balance, and stability has been minimally explored. Mobility, defined as the ability to move freely and efficiently, is a key determinant of physical independence and quality of life (Sunde et al., 2021; Elliott & Green, 2024). Similarly, balance and stability are essential for maintaining postural control and preventing falls. Current literature has inadequately addressed whether BFR training can effectively improve these parameters in middle-aged adults.

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Existing studies have primarily focused on younger populations or clinical groups, such as individuals recovering from surgery or managing chronic conditions (Ma et al., 2024; Schmidt et al., 2022; VanWye et al., 2017). For example, Lim and Goh (2022) demonstrated that low-load BFR training improved lower limb strength and functional performance in older adults, while Han et al. (2024) emphasized its potential to reduce fall risk in rehabilitation contexts. However, limited research has explored the application of BFR training for middle-aged adults, a demographic that is pivotal for preventive health interventions aiming to delay or reverse physical decline.

The significance of investigating BFR training in this population lies in its ability to provide a low-intensity yet effective intervention for enhancing functional health. As Adams et al. (2023) note, early interventions during midlife have long-term implications for sustaining physical independence and reducing age-related decline. Understanding how BFR training affects mobility, balance, and stability could lead to the development of accessible, evidence-based exercise programs that promote healthy aging.

This study addresses this gap by evaluating the effects of BFR resistance training on mobility, balance, and stability in middle-aged adults. The objective is to determine whether BFR can serve as a practical intervention for enhancing these parameters, thereby offering new insights into strategies for midlife physical health. By contributing to the expanding field of innovative exercise techniques, this research aims to support healthy aging and long-term functional independence.

Key Definitions

Blood Flow Restriction (BFR) Training: A training method involving the application of external pressure to restrict venous blood flow while maintaining arterial inflow, creating a hypoxic environment to enhance muscle activation and strength gains at low-intensity loads (Saraf et al., 2022).

Mobility: The ability to move freely and efficiently, encompassing joint flexibility and movement coordination (C.O. Spine and Joint, 2024).

Balance: The ability to maintain postural control and equilibrium during both static and dynamic activities (AbuEid et al., 2024).

Stability: The ability to counter disturbances in body positioning during movement (C.O. Spine and Joint, 2024; AbuEid et al., 2024).

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Materials and Methods

Study design

This study employs a cross-sectional design aimed at evaluating the effects of Blood Flow Restriction (BFR) resistance training on essential physical functions, including mobility, balance, and stability.

Participants

The sample size of participants was determined using Cochran's formula, taking into account a confidence level of 95%, a power of 80%, and an alpha of 0.05. From the total population of 54 middle-aged males who responded to the advertisements and invitations to participate in the study, a sample of 48 subjects was selected based on the calculated sample size. These participants were then randomly divided into two groups, BFR group 24 participants and control group 24 participants. The characteristics of the participants are presented in Table 1.

Table 1. Characteristics of the participants

Variable	BFR (N=24)	CON (N =24)	Whole Group (N=48)	Skewness
	Mean ± SD	Mean ± SD	Mean ± SD	
Age (year)	55.86 ± 2.1	55.58 ± 1.6	55.72 ± 1.85	1.40
Height (m)	1.75 ± 0.07	1.73 ± 0.04	1.74 ± 0.055	0.46
Mass (kg)	72.45 ± 8.87	74.50 ± 7.48	73.47 ± 8.18	0.94
Body-mass index (kg/m^2)	23.65 ± 2.98	24.87 ± 2.24	24.26 ± 2.61	0.98

Eligibility Criteria

Participants consisted of middle-aged males aged 53–59 years, recruited from the Seasons Fitness Center in Amman, Jordan. The inclusion criteria were as follows:

1. Physically active individuals without a history of musculoskeletal disorders in the lower or upper limbs.
2. No history of neurological, psychological, or cardiovascular conditions.
3. Non-smokers and abstainers from alcohol consumption.
4. No uncorrected impairments in motor, auditory, or visual functions.
5. An ankle-brachial index (ABI) within the normal range of 0.9 to 1.4, indicating no risk of peripheral artery disease.

Ethical Consideration

Prior to enrollment, participants were provided with detailed information regarding the study's objectives, potential benefits, and associated risks. Written

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informed consent was obtained from all individuals to confirm their voluntary participation. The research adhered to ethical guidelines as outlined by the International Journal of Exercise Science (Navalta et al., 2019) and followed the principles of the Helsinki Declaration to ensure the protection of participants' rights, safety, and well-being throughout the study (World Medical Association, 2013).

Experimental Design and Procedures

Baseline Assessments

Prior to randomization into two groups, participants underwent baseline assessments to assess their initial physical and functional status. These assessments included:

1. Physical Function Tests: Assessments were performed using the Functional Movement Screen (FMS) to assess mobility, balance, and stability.
2. Strength Assessment: Assessments were performed using a one-repetition maximum (1-RM) test of key exercises to determine baseline strength levels.

Randomization

Participants were randomized into two groups in a 1:1 ratio:

- BFR Resistance Training group (BFR group).
- Control group (CON group).

Randomization was performed using randomly permuted blocks, stratified by age and strength levels. The allocation sequence was generated using an online randomization tool (http://www.randomizer.org) by an independent researcher who was not involved in the study.

Blinding

Given the nature of the intervention, double-blinding was not possible. However, to minimize bias, the lead researcher was blinded to group assignments and primary outcome data throughout the data collection and analysis phases.

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Intervention

BFR Group

Participants in the Blood Flow Restriction (BFR) group completed a 12-week resistance training program, performed three times per week on non-consecutive days. Each session comprised four exercises targeting both the upper and lower limbs:

1. Squat.
2. Leg press (45°).
3. Supine press.
4. Biceps curl.

The training protocol adhered to the guidelines set by the American College of Sports Medicine (American College of Sports Medicine, 2009), and included:

- Three sets of 10 repetitions per exercise.
- Rest periods of 60 seconds between sets and 120 seconds between exercises.

The training load was determined through a 30-repetition maximum (30-RM) test. Blood flow restriction was implemented using H+ curved BFR cuffs calibrated to 50% of each participant's limb occlusion pressure (LOP). Limb occlusion pressure was measured using a Doppler ultrasound to ensure accuracy and participant safety. The cuffs remained inflated during exercises and rest periods and were deflated between exercises to minimize risks and ensure safety throughout the session.

Control Group

Participants in the CON group maintained their traditional exercise routine, which included the same four exercises performed by the BFR group, without any additional interventions for the 12-week study period. To address ethical considerations, they were offered the opportunity to participate in a BFR resistance training program upon completion of the study.

Outcome Measures

Physical function was evaluated using the Functional Movement Screen (FMS), a comprehensive tool designed to assess seven movement patterns across four key physical function elements:

1. **Balance Patterns:**
   - Overhead deep squat (DS)
   - Hurdle step (HS)
   - Inline lunge (ILL)
2. **Mobility Patterns:**
   - Shoulder mobility (SM)

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- Active straight leg raise (ASLR)

3. **Stability Patterns:**
    - Trunk stability pushup (TS)
    - Rotary stability (RS)

Each movement pattern was scored on a scale of 0–3, with a maximum total FMS score of 21. Scores were further categorized as follows:

- **Balance:** 0–9
- **Mobility:** 0–6
- **Stability:** 0–6

This structured scoring system provided a detailed analysis of participants' physical function and movement quality (AbuEid et al., 2024)

Data Collection and Reliability

All raters completed comprehensive training on the FMS protocol to ensure consistency and accuracy in evaluations. A calibration session was conducted to standardize assessment procedures across all raters. Inter-rater reliability was assessed using the Intraclass Correlation Coefficient (ICC), demonstrating a high level of agreement among raters (refer to Appendix 1).

Statistical Analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS) version 23 (IBM Inc., Chicago, IL, USA). Descriptive statistics were used to summarize participant characteristics. Paired t-tests assessed within-group changes, while independent t-tests compared differences between groups. Effect sizes (Cohen’s d) were calculated to determine the magnitude of differences. Statistical significance was set at $p < 0.05$.

Results

This section presents the findings of the study investigating the effects of BFR resistance training on mobility, balance, and stability in middle-aged adults. Results are summarized in tables and figures for clarity and ease of comparison.

Baseline Functional Performance

Table 2 shows the baseline Functional Movement Screen (FMS) scores for both the BFR and CON groups, including subcategories for mobility, balance, and stability, as well as the statistical comparisons between the groups.

Table 2 Baseline (pre) FMS scores and differences summary

Subcategory	BFR Group (M±SD)	CON Group (M±SD)	p-value
Balance (DS)	2.12±0.85	2.38±0.58	0.24
Balance (HS)	1.96±0.55	2.12±0.74	0.38
Balance (ILL)	1.79±0.78	1.88±0.80	0.72
Total Balance	5.88±1.30	6.38±1.35	0.20
Mobility (SM)	2.42±0.58	2.25±0.53	0.31
Mobility (ASLR)	1.75±0.61	1.96±0.20	0.12
Total Mobility	4.17±0.92	4.21±0.59	0.85
Stability (RS)	1.75±0.61	1.71±0.55	0.80
Stability (TS)	2.42±0.58	2.38±0.58	0.80
Total Stability	4.17±0.92	4.08±0.65	0.71

Training Intervention Outcomes

Table 3 provides a summary of within-group changes (pre- vs. post-intervention) and between-group differences (post-intervention) in FMS scores.

Table 3 Pre- and Post-Intervention FMS Scores

Subcategory	BFR Group Pre M±SD	BFR Group Post M±SD	BFR Group p-value	CON Group Pre M±SD	CON Group Post M±SD	CON Group p-value	Effect Size (Cohen's d)
Total Balance	5.88±1.30	7.21±1.18	0.001	6.38±1.35	6.67±1.31	0.09	BFR: 1.03, CON: 0.22
Total Mobility	4.17±0.92	4.04±0.46	0.57	4.21±0.59	4.12±0.54	0.62	BFR: -0.14, CON: 0.07
Total Stability	4.17±0.92	5.25±0.61	<0.001	4.08±0.65	4.25±0.61	0.33	BFR: 1.18, CON: 0.25

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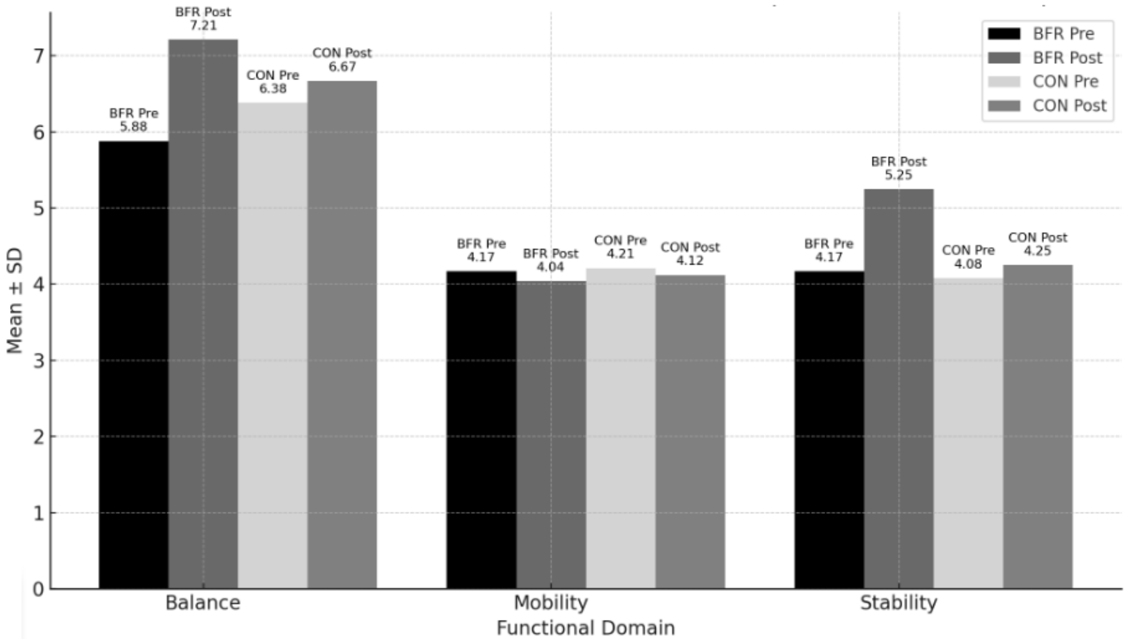

Figure 1 illustrates within-group changes (pre- and post-intervention) in total FMS scores for balance, mobility, and stability for both groups.

Detailed Analysis by Functional Domain

Balance

- The BFR group demonstrated significant improvements across all balance tests:
  - DS: +0.34 points ($p < 0.05$)
  - HS: +0.42 points ($p < 0.05$)
  - ILL: +0.59 points ($p < 0.01$)
- Control group showed minor improvements without statistical significance.

Stability

- Total stability scores in the BFR group increased significantly from 4.17 to 5.25 ($p < 0.001$).
- RS and TS sub-tests showed notable improvements in the BFR group compared to minimal changes in the control group.

Mobility

- BFR group showed an improvement in ASLR (from 1.75 to 2.13, $p < 0.05$), while the control group exhibited negligible changes.
- SM scores in the BFR group decreased slightly post-intervention, indicating enhanced efficiency.

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Discussion

The findings of this study collectively underscore the transformative potential of BFR resistance training in improving mobility, balance, and stability among middle-aged adults. These three functional domains are crucial for maintaining independence, reducing fall risk, and enhancing overall quality of life. The observed improvements highlight the unique advantages of BFR training in addressing age-related declines in physical function through low-intensity, high-adaptation protocols.

The significant gains in balance (mean change: +1.33, $p < 0.001$) and stability (mean change: +1.08, $p < 0.001$) emphasize the efficacy of BFR training in promoting postural control and core strength. Balance improvements were observed across all subtests, including the Deep Squat (DS), Hurdle Step (HS), and Inline Lunge (ILL), which collectively reflect dynamic and static balance. Similarly, stability gains were marked by improvements in both the Rotary Stability (RS) and Trunk Stability Push-Up (TS) tests, indicating enhanced core strength and the ability to counteract postural disturbances.

Mobility outcomes were more nuanced, with significant improvements in the Active Straight Leg Raise (ASLR) test for the BFR group (pre: 1.75 ± 0.61, post: 2.13 ± 0.58, $p < 0.05$). This suggests better flexibility and range of motion in the lower body. However, changes in the Shoulder Mobility (SM) test were negligible, indicating that upper body mobility may require more targeted interventions.

The control group showed minimal improvements across all functional domains, underscoring the unique benefits of BFR training in promoting functional gains through low-intensity exercise.

The observed improvements in mobility, balance, and stability are underpinned by the physiological adaptations induced by BFR training:

1. **Enhanced Neuromuscular Activation:** The hypoxic environment created during BFR training stimulates greater motor unit recruitment, which is critical for improving postural control, dynamic stability, and coordinated movement (Cognetti et al., 2022; Saraf et al., 2022).
2. **Increased Proprioceptive Feedback:** BFR training enhances sensory input from muscles and joints, leading to improved proprioception and movement accuracy, especially in balance and stability tasks (Mirzayev & Levitt, 2024).
3. **Core Engagement and Strength:** The inclusion of compound movements like squats and lunges in the BFR protocol contributed to greater core strength, which is foundational for both stability and mobility (Han et al., 2024).
4. **Flexibility and Range of Motion:** Lower body mobility improvements, particularly in the ASLR test, are likely due to increased hamstring extensibility and pelvic stability, driven by the unique metabolic demands of BFR training.

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These physiological mechanisms explain the differential improvements across functional domains, with significant gains in tasks targeting lower body mobility and overall balance and stability.

This study's findings align with and expand upon existing research on BFR training:

- **Balance:** Lim and Goh (2022) reported significant lower limb strength and balance improvements in older adults following BFR training. This study corroborates their findings but extends the application to a middle-aged population, emphasizing dynamic balance enhancements in tasks such as the ILL test.
- **Stability:** The results align with Schmidt et al. (2022), who noted increased core stability and postural control following BFR training in clinical populations. This study broadens the scope by demonstrating similar benefits in a healthy, non-clinical demographic.
- **Mobility:** While mobility outcomes were less pronounced compared to balance and stability, the improvements in ASLR scores support findings by Elliott and Green (2024), who highlighted BFR's role in enhancing lower body flexibility and range of motion.

In contrast, negligible changes in SM scores suggest that upper body mobility may not benefit as directly from BFR training, highlighting the need for tailored interventions for this domain.

The results have several practical implications for promoting functional health in middle-aged adults:

1. **Fall Prevention:** Enhanced balance and stability reduce fall risk, a leading cause of injury and loss of independence in aging populations. BFR training offers a preventive strategy that is accessible and effective.
2. **Daily Functionality:** Improvements in balance, stability, and lower body mobility translate into better performance of daily activities, such as walking, stair climbing, and bending.
3. **Rehabilitation and Accessibility:** The low-intensity nature of BFR training makes it particularly suitable for individuals unable to engage in traditional high-intensity resistance exercises due to joint or physical limitations.

The findings align with studies demonstrating BFR's efficacy in improving strength, balance, and stability (Lim & Goh, 2022; Han et al., 2024). However, this study diverges by focusing on functional outcomes in a middle-aged, healthy population rather than younger or clinical cohorts. By demonstrating significant gains in balance, stability, and mobility, this research provides novel insights into the preventive potential of BFR training for addressing age-related functional decline.

Building on these findings, future research should explore:

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1. **Long-Term Outcomes:** Assessing whether the observed functional gains are sustained over extended periods of BFR training.
2. **Tailored Interventions:** Developing protocols that target upper body mobility to complement the lower body and core benefits.
3. **Diverse Populations:** Examining the efficacy of BFR training across different age groups, genders, and individuals with specific balance or mobility impairments.
4. **Comparative Studies:** Comparing BFR training with traditional balance and mobility-focused exercises to identify the most effective approaches.

Conclusions

The findings of this study highlight the significant potential of Blood Flow Restriction (BFR) resistance training as a practical, low-intensity intervention to enhance critical physical functions—balance, stability, and mobility—in middle-aged adults. These improvements are especially noteworthy for addressing age-related declines in functional independence and fall risk. By leveraging the physiological benefits of BFR training, this research establishes a foundation for integrating this method into preventive and rehabilitative fitness programs for middle-aged populations.

The results infer that BFR training may be uniquely suited to individuals unable to perform traditional high-intensity resistance exercises due to joint or mobility limitations. Furthermore, the observed improvements in neuromuscular coordination and dynamic stability suggest that BFR training could have applications beyond the scope of this study, including rehabilitation and sports performance.

Future research should build on these findings by:

1. Investigating the long-term effects of BFR training on fall prevention and overall physical independence.
2. Exploring its application across different age groups, particularly older adults and females, to validate its broader applicability.
3. Conducting comparative studies to evaluate the relative efficacy of BFR training against other low-intensity functional interventions.

These directions will refine the understanding of BFR training’s potential and contribute to developing comprehensive, evidence-based strategies for promoting healthy aging and functional longevity.

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Appendix

Appendix 1: Assessment of Inter-Rater Reliability Using Intraclass Correlation Coefficients (ICCs)

We utilize a two-way random-effects model (ICC 2,1) to assess inter-rater reliability to calculate intraclass correlation coefficients (ICCs). Table 1 presents the ICCs for single and average measures from two different tests, illustrating the consistency and dependability of evaluations provided by two raters.

Table 1 Intraclass Correlation Coefficients (ICCs) for Evaluative Consistency Across Bifurcated Tests

Test Number	Measure Type	ICC (2,1)	95% CI Lower Bound	95% CI Upper Bound	F Test Value	df1	df2	Sig
First Test	Single Measures	0.914	0.788	0.966	25.222	19	19	.001
First Test	Average Measures	0.955	0.881	0.983	25.222	19	19	.001
Second Test	Single Measures	0.922	0.813	0.968	24.548	19	19	.001
Second Test	Average Measures	0.959	0.897	0.984	24.548	19	19	.001

Note: The (ICC 2,1) values represent a two-way random-effects model where the effects attributable to subjects and the specific measures under consideration are treated as random components. Type A ICCs reflect an absolute agreement metric, while Type C ICCs are predicated on a consistency framework. Importantly, the calculation of Type C ICCs omits the between-measure variance from the variance component in the denominator, focusing solely on within-measure consistency.

Table 1 uses a two-way random-effects model (ICC 2,1), indicating that the effects of raters and measures are considered random.

In the First Test, Single Measures, An ICC of 0.914 suggests high reliability in the ratings of different raters. The 95% confidence interval (CI) from 0.788 to 0.966 indicates that if the study were repeated with different raters from the same population, we would expect the ICC to fall within this range 95% of the time. The F test is significant ($p = .001$), further supporting the reliability of the ratings. First Test, Average Measures: The ICC increases to 0.955, which shows an even higher level of agreement among raters when average measures are considered. The narrower CI of 0.881 to 0.983 reinforces this high reliability. The significance of the F test remains strong.

In the Second Test, Single Measures, The ICC is slightly higher at 0.922 than the first, indicating consistently high reliability across tests. The CI range of 0.813 to 0.968 remains tight, suggesting confidence in this estimate. Second Test, Average Measures: The ICC is again higher for average measures at 0.959, which indicates that averaging the ratings can reduce the impact of any random effects that might influence individual ratings. The CI of 0.897 to 0.984 and the significant F test value corroborate the high inter-rater reliability.

The note indicates that people's and measures' effects are random, which means the model accounts for variability among raters and the items being rated. Type A ICCs are calculated based on absolute agreement, suggesting that the raters are in strong agreement not just in rank order but also in the actual values of their ratings. Type C ICCs, based on consistency, would exclude between-measure variance from the denominator variance; however, this does not appear to be directly applicable to the results presented in Table 1.

In conclusion, the high ICC values across single and average measures, narrow confidence intervals and significant F test results indicate excellent inter-rater reliability. This suggests that the ratings are consistent and reproducible across different raters, lending credibility to the evaluation process used in the study.

Delving into test-retest and intra-rater reliability, Table 2 presents a nuanced analysis of the consistency in evaluations performed by the respective raters across the two testing intervals. The reliability was quantified via the ICC (3,1) model, which endorses a two-way mixed-effects analytical framework.

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Table 2 Intraclass Correlation Coefficient Raters One and Two for the First and Second Test

Rater	Measure Type	ICC (3,1)	95% CI Lower Bound	95% CI Upper Bound	F Test Value	df1	df2	Sig
1	Single Measures	.937	.848	.975	29.345	19	19	.001
1	Average Measures	.968	.918	.987	29.345	19	19	.001
2	Single Measures	.799	.566	.915	8.896	19	19	.001
2	Average Measures	.889	.722	.956	8.896	19	19	.001

Note: The ICC (3,1) delineates a mixed-effects model in which subject effects are modelled as random and measurement effects as fixed. The Type A ICC, employed herein, quantifies absolute agreement without assuming interaction effects, which remain un-estimated due to methodological constraints.

Table 2 presents the test-retest and intra-rater reliability assessment for two raters across two tests. It employs a two-way mixed-effects model (ICC 3,1), suggesting that the people effects (i.e., differences among raters) are considered random. In contrast, the effects of the measures are treated as fixed. This model choice is appropriate when the raters are a random sample from a larger population of possible raters and when the measure (e.g., the test or item being rated) is the same across all raters and is the primary interest of the reliability estimation. The ICC (3,1) also allows for assessing the consistency of ratings within raters across time, which indicates both intra-rater and test-retest reliability.

In Rater 1, Single Measures, The ICC of .937 indicates an excellent level of agreement in this rater's scores between the two testing occasions, suggesting very high intra-rater reliability. The confidence interval is quite narrow (.848 to .975), indicating that we can be very confident about the reliability of this estimate. The F test result is significant ($p = .001$), confirming the strong reliability of the rater's evaluations. Rater 1, Average Measures, With an ICC of .968, the average measures for Rater 1 display even higher reliability than the single measures. This is typical because average scores are more stable and less affected by random error. The confidence interval (.918 to

.987) remains narrow, reflecting high precision in the reliability estimate. The significance of the F test remains robust, supporting the reliability.

In Rater 2, Single Measures: The ICC for Rater 2's single measures is .799, which is still considered good reliability but is noticeably lower than that of Rater 1. The wider confidence interval (.566 to .915) suggests more uncertainty about this estimate, which could indicate variability in Rater 2's scoring consistency over time. Rater 2, Average Measures, the ICC improves to .889 for the average measures, which, as with Rater 1, indicates that averaging across measures improves reliability by reducing the impact of random errors. The confidence interval (.722 to .956) is narrower than for the single measures but still wider than for Rater 1, reflecting greater variability in Rater 2's ratings.

The note clarifies that the ICC estimates are based on absolute agreement and do not assume an interaction effect because it is not estimable. This is important as it affects the interpretation of the ICC values — with absolute agreement, the focus is on how close the ratings are in absolute terms, not just their rank order.

In summary, Table 2 shows excellent intra-rater and test-retest reliability for Rater 1, with high consistency in their ratings across tests. Rater 2 shows good reliability but with more variability than Rater 1. Overall, the table suggests that the ratings are reasonably stable over time and consistent within each rater, which is crucial for the reliability of the study's measurements.

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