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Impact of Inspiratory Muscle Warm-up on the Reliability of a Novice Evaluator. Effect of Sex and Body Composition

Impacto del Calentamiento Muscular Inspirador en la Confiabilidad de un Evaluador Novato. Efecto del Sexo y la Composición Corporal

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SUMMARY: The reliability of maximal inspiratory pressure (MIP) measurementas an indicator of respiratory muscle motor capacity has been debated in both normal and impaired respiratory function contexts. This study aimed to determine whether a specific warm-up of the inspiratory muscles produces significant changes in inter-rater reliability of MIP measurement in healthy individuals between a novice kinesiology (NK) and an expert (EK). A secondary objective was to examine whether sex and body composition influence reliability outcomes. Fifty-seven university students were recruited. All participants underwent MIP assessment by two evaluators. The expert evaluator followed the ATS/ERS protocol, whereas the novice evaluator applied the ATS/ERS protocol plus inspiratory muscle warm-up. Group allocation was randomized to minimize learning effects. Fifty-four participants were included in the analysis. The intraclass correlation coefficient (ICC) for the total sample was 0.896 (95 % CI: 0.814–0.942; p = 0.0001). Among overweight participants and males, a small clinical difference favored the EK (Cohen's d = 0.240 and 0.309, respectively). In the multivariate analysis, sex and number of attempts significantly contributed to MIP values for the NK. Specifically, identifying as female decreased MIP by 23.532 cmH_2O, and each additional attempt increased MIP by 6.717 cmH_2O. High inter-rater reliability was observed regardless of sex or body composition. A small clinical difference between evaluators was noted in the overweight and male groups. For the NK, the multivariate model revealed a significant interaction between sex and number of attempts in predicting MIP values.

KEY WORDS: Inspiratory muscle; warm-up; reliability; novice evaluator; sex; body composition.

INTRODUCTION

The reliability of maximal inspiratory pressure (MIP) measurement, as an indicator of respiratory muscle motor capacity, has been examined across diverse clinical and functional contexts, including acute respiratory dysfunction (Walterspacher *et al*., 2016), patients approaching extubation (Kuo *et al*., 2006), chronic respiratory disease such as chronic obstructive pulmonary disease (COPD) (Kofod *et al*., 2019), and athletic performance settings (Torres *et al*., 2017). More recently, growing interest has focused on understanding how ancestral and sociocultural factors influence reference values (Rodrigues *et al*., 2017). In this regard, the use of robust statistical procedures to confirm the stability of obtained values is essential for an accurate interpretation of respiratory muscle performance (Aldrich & Spiro, 1995).

Sclauser Pessoa *et al*. (2014) reported that several investigations have attempted to standardize MIP assessment procedures (Pessoa *et al*. 2014). In this context, the greater the mastery of the testing technique, the higher the reproducibility of the data (Farooqi *et al*., 2020). Rodríguez

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(2015) demonstrated that experienced evaluators show regular-to-good reliability in MIP assessment (intraclass correlation coefficient [ICC] = 0.70) (Rodríguez, 2015). Conversely, Yakut *et al*. (2022) compared two home-based inspiratory training programs high-intensity interval training versus moderate-intensity continuous training and observed improvements in MIP, functional capacity, and quality of life in both groups. These findings were attributed, at least in part, to learning effects and the development of technical proficiency for MIP performance; however, neither the nature nor the duration required to achieve such learning was explored (Yakut *et al*., 2022).

Warm-up prior to physical effort is widely accepted, as it induces physiological, psychological, and biomechanical readiness for activity beyond routine demands (McGowan *et al*., 2015; Sannicandro *et al*., 2021). Specifically, Adaos *et al*. (2015) compared MIP assessment across three groups: a standard American Thoracic Society/ European Respiratory Society (ATS/ERS) protocol, a protocol incorporating test familiarization, and a protocol including inspiratory muscle warm-up. Their findings indicated that warm-up was the most efficient strategy, enabling participants to achieve peak values while reporting lower perceptions of fatigue and dyspnea (Adaos *et al*., 2015). Clinically, ensuring the stability of MIP results particularly those representing true maximal effort may enhance the precision of clinical decision-making and the effectiveness of targeted interventions.

Body composition and sex have also been shown to influence MIP values. Studies have demonstrated an inverse relationship between increasing body mass index (BMI) and MIP. However, other evidence suggests fiber-type remodeling in respiratory muscles among individuals with obesity, potentially altering inspiratory pressure generation. Regarding sex-related differences, women have smaller lungs and airway diameters compared with men of equivalent height (Suárez *et al*., 2024), resulting in reduced alveolar surface area for gas exchange and a greater likelihood of expiratory flow limitation. Although this limitation does not inherently impair ventilation, it shifts breathing toward total lung capacity (TLC), thereby altering diaphragmatic geometry and reducing its length-tension advantage. Ultimately, this may increase the metabolic cost of ventilation at higher ventilatory demands, with a greater fraction of total oxygen consumption (VO_2) directed toward respiratory muscles (Archiza *et al*., 2021).

From a professional competency perspective, expert evaluators are expected to demonstrate consistent technical reliability, grounded in reflective practice and ongoing self-evaluation attributes not immediately established in novice practitioners but rather developed through experience. Based on this rationale, it can be hypothesized that incorporating a specific inspiratory muscle warm-up may reduce the natural variability observed between expert and novice evaluators in MIP measurement. Consequently, inter-rater reliability should improve when warm-up is included.

Therefore, the objectives of this study were to determine whether specific inspiratory muscle warm-up produces significant changes in inter-rater reliability of MIP measurement in healthy individuals between a novice kinesiology (NK) and an expert (EK), and secondarily, to assess whether sex and body composition influence reliability outcomes.

PATIENTS AND METHOD

Study Design. This exploratory cross-sectional study was conducted at the Ventilatory Function and Dysfunction Laboratory of Universidad Católica del Maule (UCM).

Participants. Sample size was calculated using eNe 3.0 software. A statistical power of 80 % and a significance level of 5% were assumed, considering a mean MIP of -128 cmH_2O and a standard deviation of -20 cm H_2O in the reference population (Pessoa *et al*., 2014). The estimated sample size was 51 participants; however, assuming a 10 % attrition rate, a total of 57 individuals were recruited.

Eligible participants were ≥18 years old, free of clinical signs of acute respiratory disease, and demonstrated normal spirometric values. Exclusion criteria included smoking, morphological abnormalities of the thoracic cage or spine, and body mass index (BMI) >30 kg/m^2. All participants read and signed informed consent forms approved by the UCM Ethics Committee (23/2016).

Procedures

Spirometry. Spirometry was performed using a plethysmograph (Platinum Elite DL®, MedGraphics, St. Paul, MN, USA). The highest forced vital capacity (FVC) value from three acceptable and reproducible maneuvers, according to American Thoracic Society (ATS) criteria, was recorded. The variables analyzed included FVC, forced expiratory volume in one second (FEV_1), FEV_1/FVC ratio, and forced expiratory flow between 25 % and 75 % of FVC (FEF25-75 %) (Graham *et al*., 2019) (Fig. 1).

Order of MIP Evaluation. Participants were registered in a database and randomly assigned via an online tool to begin testing either with the NK or the EK to minimize learning effects (Fig. 1). All participants were assessed by both evaluators.

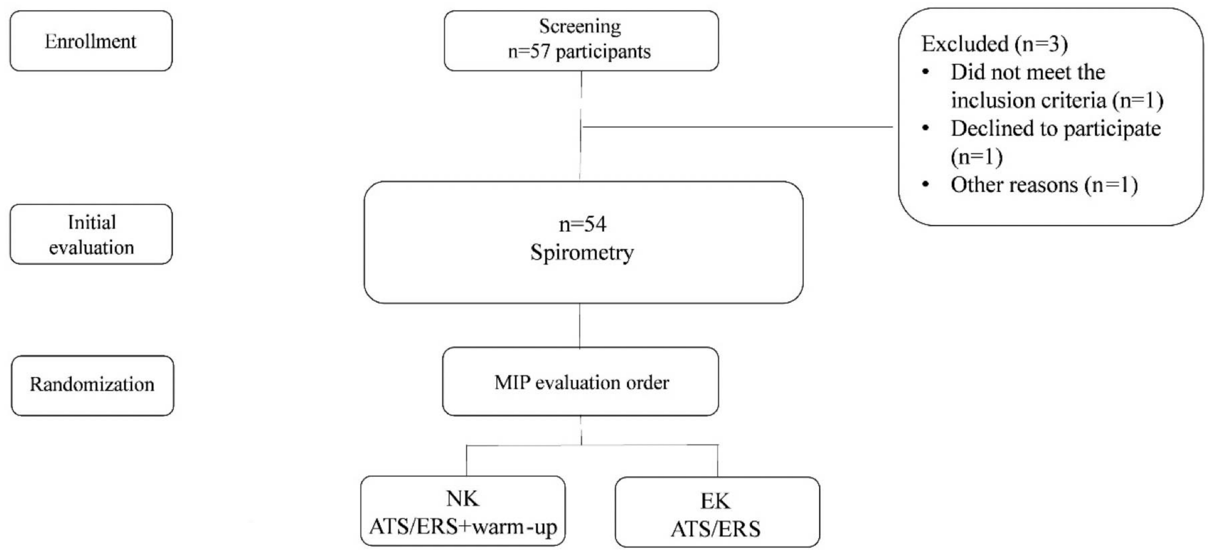

Fig. 1. Flow diagram of the studied sample. NK: novice kinesiologist evaluator; EK: expert kinesiologist evaluator; MIP: Maximal inspiratory pressure; ATS/ERS: American Thoracic Society/European Respiratory Society protocol.

Evaluators

Novice Kinesiology (NK): A licensed physical therapist whose degree had been obtained within the previous year and who was actively practicing respiratory physiotherapy in a rehabilitation unit, respiratory care service, or intensive care setting (Fig. 1).

Expert Kinesiology (EK): A Ministry of Health (MINSAL) certified physical therapist with 15 years of professional experience and head of the Ventilatory Function Laboratory at the UCM Department of Kinesiology (Fig. 1).

Testing Protocols

ATS/ERS Standard ProtocoL. MIP was measured using a body plethysmograph (Platinum Elite series®, MedGraphics) in a quiet room, with participants seated. A nose clip was applied and a mouthpiece positioned between the teeth. After five tidal breaths, participants exhaled to residual volume and then inhaled maximally against an occluded airway. The three highest values with ≤5% variability were recorded (ATS/ERS, 2002).

Warm-Up + ATS/ERS Protocol. This procedure comprised two stages: (i) inspiratory muscle warm-up following Lomax and McConnell. A Müller maneuver was first performed to determine baseline workload, followed by two sets of 30 repetitions at 40 % of baseline MIP using the PowerBreathe Sport Performance Plus® device, with 2-minute rest intervals (Lomax & McConnell, 2009); and (ii) subsequent MIP assessment using the ATS/ERS protocol (ATS/ERS, 2002).

Statistical Analysis

Descriptive statistics are presented as mean ± standard deviation. Variable distribution was assessed using the Shapiro–Wilk test, confirming normality. Test-retest reliability was evaluated using the intraclass correlation coefficient (ICC) with 95 % confidence intervals (95 % CI). Analyses were conducted using SPSS version 15.0, and graphical outputs were generated using GraphPad Prism version 5.0.

Effect size was calculated using Cohen's d, interpreted as follows: <0.20 = negligible; 0.20–0.49 = small; 0.50–0.79 = medium; ≥0.80 = large. A multiple linear regression model was performed including both evaluators, with MIP as the dependent variable and sex (female as event of interest), number of attempts, and BMI as independent variables. A stepwise method was applied to identify significant predictors. Statistical significance was set at $p < 0.05$.

RESULTS

Of the 57 participants enrolled, 54 were included in the final analysis. Three individuals were excluded due to: (i) not meeting inclusion criteria (n = 1), (ii) declining to participate (n = 1), and (iii) other reasons (n = 1) (Fig. 1). Table I displays baseline characteristics of the study sample. Mean age and BMI were 20.39 ± 1.45 years and 23.43 ± 2.26 kg/m^2, respectively. Spirometric values were within normal ranges, with FVC 4.20 ± 1.23 L (107.56 ± 13.73 % predicted) and FEV_1 3.64 ± 0.61 L (102.13 ± 11.35 % predicted) (Table I).

Table I. Anthropometric and lung function characteristics of the sample.

Variable	Mean ± SD
Age (years)	20.39 ± 1.45
Weight (kg)	64.74 ± 10.54
Height (m)	1.65 ± 0.08
BMI (kg/m^2)	23.43 ± 2.26
FVC (L)	4.20 ± 1.23
FVC (% predicted)	107.56 ± 13.73
FEV_1 (L)	3.64 ± 0.61
FEV_1 (% predicted)	102.13 ± 11.35
FEF_{25}–$_{75}$ (L/s)	3.65 ± 0.83
FEF_{25}–$_{75}$ (% predicted)	87.0 ± 19.53

BMI: body mass index; FVC: forced vital capacity; FEV_1: forced expiratory volume in the first second; FEF_{25}–$_{75}$: forced expiratory flow between 25 % and 75 % of FVC.

Table II. Intraclass correlation coefficient.

Group	Expert (cmH_2O)	Novice (cmH_2O)	ICC (95 % CI)	*p*-value
Total sample	117.06 ± 32.48	110.70 ± 31.97	0.896 (0.814–0.942)	0.0001
Overweight	121.6 ± 33.8	113.5 ± 33.5	0.872 (0.740–0.937)	0.001
Obese	106.0 ± 27.66	103.9 ± 29.34	0.933 (0.792–0.979)	0.001
Male	127.0 ± 38.35	115.8 ± 34.00	0.966 (0.906–0.987)	0.0001
Female	111.1 ± 27.38	105.5 ± 31.83	0.817 (0.815–0.913)	0.0001

ICC: Intraclass correlation coefficient.

The intraclass correlation coefficient (ICC) for the total sample was 0.896 (95 % CI: 0.814–0.942; p = 0.0001). Subgroup analyses by body composition and sex yielded the following ICC values: overweight 0.872 (95 % CI: 0.740–0.937; p = 0.001), obese 0.933 (95 % CI: 0.792–0.979; p = 0.001), males 0.966 (95 % CI: 0.906–0.987; p = 0.0001), and females 0.817 (95 % CI: 0.815–0.913; p = 0.0001) (Table II).

Regarding clinical differences, overweight participants demonstrated a small clinical difference in favor of the EK, however, the NK required significantly fewer attempts. Among males, a similarly small clinical difference favoring the EK was observed, although the number of attempts did not differ significantly between evaluators. In contrast, among females, the NK required significantly fewer attempts (Table III).

Table III. Subgroup Analysis by body mass index category.

Group	Variable	Expert	Novice	Cohen's *d*	*p*-value
Overweight	MIP (cmH_2O)	121.6 ± 33.8	113.5 ± 33.5	0.240	0.320^t
	Attempts (repetitions)	6 (3–11)	4 (3–7)	—	0.048^{MW}
Obese	MIP (cmH_2O)	106.0 ± 27.66	103.9 ± 29.34	0.073	0.843^t
	Attempts (repetitions)	5 (3–10)	4 (3–9)	—	0.326^{MW}
Male	MIP (cmH_2O)	127.0 ± 38.35	115.8 ± 34.00	0.309	0.359
	Attempts (repetitions)	6 (3–11)	5 (3–7)	—	0.189
Female	MIP (cmH_2O)	111.1 ± 27.38	105.5 ± 31.83	0.188	0.650
	Attempts (repetitions)	6 (3–10)	4 (3–9)	—	0.035

MIP: maximal inspiratory pressure; cmH_2O: centimeters of water; t: independent samples t-test; MW: Mann–Whitney U test.

Table IV. Multiple linear regression for improvement in specific airway resistance.

Model						**F**	***p***	**R^2**
Expert						9.082	**0.038**	0.410
		95 % IC						
Variable	B	LL	UL	SE	*p*			
Sex (Female)	0.380	-23.566	24.326	11.896	0.975			
Attempts	4.361	0.241	8.482	0.047	**0.038**			
BMI	2.518	-1.325	6.361	1.909	0.194			
Constant	36.624	-58.551	131.978	47.282	0.443			
						F	*p*	R^2
Novice		95 % IC				3.379	**<0.01**	0.435
Variable	B	LL	UL	SE	*p*			
Sex (Female)	-23.532	-42.233	-4.832	9.301	**0.01**			
Attempts	6.717	0.424	13.010	3.130	**0.037**			
BMI	1.921	-2.022	5.863	1.961	0.332			
Constant	44.581	-59.132	148.293	51.582	0.001			

%BF-SF: body fat percentage by skinfold measurements; %BF-BIA: body fat percentage by bioelectrical impedance analysis; 95% CI: 95% confidence interval; B: unstandardized beta coefficients; LL: lower limit; UL: upper limit; SE: standard error. Bold values denote p < 0.05.

In the multivariate analysis, sex (female), number of attempts, and BMI were included as predictors. For the EK, only number of attempts significantly contributed to MIP values, with each additional attempt increasing MIP by 4.361 cmH_2O. For the NK, both sex and number of attempts were significant predictors. Specifically, female sex was associated with a 23.532 cmH_2O decrease in MIP, while each additional attempt increased MIP by 6.717 cmH_2O (Table IV).

DISCUSSION

The aim of this study was to determine whether a specific inspiratory muscle warm-up produces significant changes in inter-rater reliability of MIP measurement in healthy individuals between a NK and an EK, and whether sex and body composition influence this process. The main findings were: (i) high reliability was observed regardless of sex and body composition, (ii) overweight participants and males demonstrated a small clinical difference in favor of the EK, (iii) the NK required significantly fewer attempts in the overweight group, and (iv) in the regression analysis, sex and number of attempts significantly influenced MIP values for the NK.

A principal purpose of warm-up is to prepare muscle tissue to achieve maximal performance. Prior activation of inspiratory muscles has been shown to enhance inspiratory muscle strength (Volianitis *et al*., 2001), which may help explain the absence of significant differences in MIP between the NK and EK. Furthermore, the NK demonstrated lower percentage variability and fewer attempts, suggesting a reduced learning effect. Collectively, these results support that specific inspiratory muscle warm-up may reduce data variability and the number of attempts required to achieve acceptable reproducibility, thereby improvingmeasurement reliability.

The high inter-rater reliability observed in this study aligns with previous evidence. Muñoz-Cofré *et al*. (2018) demonstrated excellent agreement between an EK and a student during clinical training, reporting ICC values of 0.914, 0.915, and 0.925 across successive attempts and a systematic bias of 9.2 cmH_2O favoring the EK in Bland-Altman analysis (Muñoz-Cofré *et al*., 2018). The present study extends this evidence by analyzing reliability according to nutritional status and sex (Table II), confirming consistent reliability across subgroups. Thus, inspiratory warm-up may be recommended for novice clinicians when performing MIP testing in clinical settings.

A small clinical difference in MIP values was also observed, consistent with findings from Cruickshank *et al*. (2022), who demonstrated greater improvements in maximal respiratory pressures following inspiratory warm-up compared with single or repeated testing sessions (effect size = 0.40 *vs*. 0.20, respectively) (Cruickshank *et al*. 2022). Our results complement this evidence by showing that overweight and male participants displayed small clinical differences favoring the EK (Table III).

In overweight participants, the NK required significantly fewer attempts, a finding associated with the small clinical difference in that subgroup. Adaos *et al*. (2015) compared ATS/ERS, warm-up, and test-learning protocols and found significantly higher MIP values following warm-up (Adaos *et al*., 2015). In our study, the median number of attempts was four ($p < 0.048$). This may relate to (i) respiratory biomechanics in overweight individuals characterized by a higher proportion of fast-twitch fibers with greater force capacity and (ii) physiological priming induced by the warm-up maneuver.

The regression analysis revealed that, for the NK, sex and number of attempts were significant predictors of MIP (Table IV). This partially agrees with Bairapareddy *et al*. (2021), who identified age, sex, and BMI as predictors of maximal respiratory pressure in young adults (Bairapareddy *et al*., 2021). Similarly, Moeliono *et al*. (2022) reported that thoracic expansion and sex predict MIP, suggesting thoracic expansion measurement as a feasible clinical tool (Moeliono *et al*., 2022). In our findings, female sex was associated with lower MIP values, a pattern consistent with existing literature. Additionally, each extra attempt increased MIP by 6.717 cmH_2O in the NK, potentially reflecting increased electromyographic activity following submaximal loading. Notably, our warm-up protocol mirrored that used by Hawkes *et al*., consisting of 30 repetitions at 40 % of baseline MIP (Hawkes *et al*., 2007). These results support the rationale for activating inspiratory muscles before maximal effort evaluations.

A primary limitation was the absence of a condition in which the EK also performed testing with inspiratory warm-up, which would have allowed assessment of whether warm-up influences expert performance. Additionally, the relatively narrow age range of participants limits generalizability across the lifespan.

CONCLUSIONS

High inter-rater reliability in MIP measurement was observed regardless of sex and body composition. Small clinical differences between evaluators were noted in overweight and male participants. In the NK group, sex and number of attempts were significantly associated with MIP values. These results support incorporating inspiratory muscle warm-up prior to MIP assessment, as it may enhance performance and reduce the number of attempts required to obtain reliable measurements.

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RESUMEN: La confiabilidad de la medición de la presión inspiratoria máxima (PIM), como expresión de la capacidad motora de los músculos respiratorios, ha sido un dilema que se ha estudiado en contextos de disfunción como de función respiratoria. el objetivo de esta investigación fue determinar si el calentamiento específico de los músculos inspiratorios produce cambios significativos en la confiabilidad inter evaluador en la medición de la PIM de sujetos sanos, entre un kinesiólogo novato (KN) y uno experto (KE). Se reclutaron 57 estudiantes universitarios. A todos se les midió la PIM por dos evaluadores. Un evaluador experto, que utilizó el protocolo ATS/ERS y un evaluador novato, que utilizó el protocolo ATS/ERS+ calentamiento de la musculatura inspiratoria. La asignación de grupos fue aleatorizada con el propósito de disminuir el efecto aprendizaje. Cincuenta y cuatro participantes fueron incluidos. El coeficiente de correlación intraclase (CCI) en la muestra total fue de 0,896 (IC 95 %: 0,814-0,942; p=0,0001). en el caso de los participantes con sobrepeso y de género masculino, existió una diferencia clínica menor en los resultados de la PIM en favor del KE (d de Cohen= 0,240 y 0,309, respectivamente). En el análisis multivariado, las variables que aportan de manera significativa al valor de la PIM son el sexo y el número de intentos, para el KN. Específicamente, pertenecer al género femenino disminuye la PIM en 23,532 cmH_2O y por cada intento realizado, la PIM, aumenta en 6,717 cmH_2O. Se observó una alta confiabilidad independiente de género y composición corporal, entre los evaluadores. En los grupos sobrepeso y hombres se observó una diferencia clínica pequeña, entre los evaluadores y el análisis multivariado arrojó, en el caso del KN, una interacción significativa entre el sexo y el número de intentos en el valor de la PIM.

PALABRAS CLAVE: Músculo inspiratorio; calentamiento; confiabilidad; evaluador principiante; sexo; composición corporal.

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