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What Factors Predict Upper Body Push to Pull Ratios in Professional Firefighters?

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ABSTRACT

International Journal of Exercise Science 13(4): 1605-1614, 2020. Shoulder joint injuries are common for professional firefighters. A potential cause of shoulder injury is an imbalance between anterior (push) and posterior (pull) shoulder joint musculature. Understanding what contributes to these imbalances may help to identify areas needing improvement. The purpose of this study was to investigate different push to pull (P2P) ratios and the relationships among common upper body fitness assessments, body composition, and push to pull (P2P) ratios in firefighters. Thirty-three professional firefighters completed the following testing protocol: one-repetition maximum (1RM) bench press, pull-up repetitions to failure, push-up repetitions to failure, and a body composition assessment. The endurance P2P (eP2P) was computed by dividing the number of push-up by pull-up repetitions, while strength P2P (sP2P) was the relative 1RM divided by pull-up repetitions. Bivariate relationships among variables were assessed with correlation coefficients and linear regression assessed association between eP2P and sP2P ($p \leq 0.05$). The sP2P and eP2P were not associated ($R^2 = 0.032$, $p = 0.99$). Strength P2P was related with bench press 1RM ($r = 0.80$) and push-ups ($r = 0.40$). Endurance P2P was related with pull-up repetitions ($r = -0.62$), body fat percentage ($r = 0.40$), and fat mass index ($r = 0.34$). The results of the present study suggest sP2P and eP2P ratios should not be used interchangeably. To improve sP2P and eP2P for firefighters, it is recommended to improve the strength of anterior and posterior upper body musculature, respectively, and reduce total body fat mass.

KEY WORDS: Upper body assessment, muscular fitness, tactical athlete, strength, endurance

INTRODUCTION

The estimated financial costs (lost productivity, compensation, medical expenses) as result of musculoskeletal injury in firefighters may reach upwards of $1 billion annually in the United States (30). Musculoskeletal injury risk is high in firefighters due to the physical and unpredictable nature of the occupation (24). In 2018 the National Fire Protection Association estimated approximately 29,550 musculoskeletal injuries amongst firefighters (31). These may occur while completing high-intensity occupational tasks such as tower climbs, equipment hoist, forcible entry, ladder raises, and victim rescue (27). In firefighters, sprains and strains are the most common types of injury with the upper extremities, and more specifically, the shoulder joint being a common site of injury (19).

Increased shoulder injury risk may result from an imbalance between the anterior and posterior musculature surrounding the joint (2, 5). Previous literature has investigated a push to pull ratio (P2P) of the shoulder joint based on common upper body muscular fitness assessments in recreationally trained adults (18) and athletic populations (1,20). When evaluating the upper body P2P as repetitions performed in timed push-ups and inverted bodyweight rows in a strength-trained sporting population, males and females displayed P2P of 1.6 to 2.7, respectively (18). Pearson et al. (20) compared forces, velocity and power during a one-repetition maximum (1RM) bench press compared to a 1RM bench pull. Interestingly, while the 1RM strength was found to be greater for pushing than pulling, the velocity and power output of pulling was found to be greater than that of pushing for heavier loads (20). Baker and Newton (1) investigated vertical pulling strength in a study that compared a 1RM bench press to 1RM pull-up in professional rugby players. It was reported that the 1RM bench press was approximately 98% of 1RM pull-up in these well-trained participants and concluded that practitioners should consider the P2P when prescribing exercise to address upper extremity imbalances (1).

Although P2P of the shoulder joint has previously been studied in a variety of populations (1,18,20), to our knowledge no study has investigated this P2P amongst professional firefighters. The fitness assessments, typically required during firefighter training academies and annual testing as part of department policies, often include common upper body muscular fitness tests of 1RM bench press, pull-ups, and push-ups (9,10,14,25). Therefore, despite prior investigations utilizing horizontal push and pull exercises to create P2P, it may be more practical for firefighters to utilize a horizontal push (push-up, bench press) and vertical pull (pull-ups), since these tests are commonly being administered. Furthermore, it has been recently reported that upper body push and pull strength and endurance are important determinants of the ability of firefighters to perform occupational tasks (8,10). Thus, it may be important when examining P2P to consider the agreement between P2P from strength and endurance assessments. Although majority of prior literature has evaluated P2P using strength assessments, the push-up and pull-up assessments are easy to conduct and require little equipment making them easily and more commonly administered to firefighters. A recent review of previous literature pertaining to the fitness of firefighters in regards to their ability to perform occupational tasks concluded that both upper body strength and endurance were important factors to assess (8). Therefore, the purpose of this study was to investigate P2P from strength and endurance assessments, as well as their agreement. Additionally, considering the importance of push and pull abilities in firefighters, a secondary purpose of this study was to examine potential variables related to the P2P performances.

METHODS

Participants

A priori power analysis determined that a minimum sample size of 26 participants was needed according to correlation procedures with moderate effects ($r = 0.5$), $p = 0.05$, and power = 0.80. Thirty-seven participants initially completed the procedures required of the study, but due to the purpose of the study any participant who was unable to perform 1 pull-up was removed from the analysis (male=3 [8.1%], female=1 [25.0%]). In total, thirty-three (male=30 [90%], female=3 [10%]) Firefighters were included in the data analysis (Table 1). All participants were employed by Prince William County, Virginia and had graduated from their respective academies. The inclusion criteria required participants to: 1) not have a surgery or injury in the past 3 months; 2) be able to run, as well as perform a push-up and pull-up without pain; 3) have no history of cardiovascular disease, pulmonary disease, renal disease, or metabolic disease and 4) be performing on average 30 minutes of physical activity per day (structured exercise or activities of daily living). Firefighters who did not meet the aforementioned criteria were excluded from the study. Each participant was informed of the risk of the study and signed an informed consent. The study was approved by the University's Institutional Review Board. All procedures complied to the ethics statements described in previous work (17).

Protocol

Each participant was tested individually, during a single testing session, and were asked to refrain from food and drink, aside from water, for 2 hours prior to testing, refrain from strenuous exercise for 48 hours prior to testing, and to wear appropriate workout attire. Testing began with anthropometric measurements and body composition assessment. Participants then completed a standard, supervised, warm-up prior to performing the following sequence of upper body fitness assessments: 1RM bench press; pull-ups to failure; push-ups to failure. Exactly 5 minutes of rest were given to participants following each upper body assessment. The rest length was determined from pilot testing of the protocol and anecdotally participants self-reported feeling fully recovered within 3 to 4 minutes following each assessment. The strength P2P (sP2P) was calculated as bench press 1RM divided by the estimated pull-up 1RM, while the endurance P2P (eP2P) was calculated as the number of push-ups divided by the number of pull-ups. All participants were supervised by a researcher who was a Certified Strength and Conditioning Specialist (CSCS). The testing results were analyzed using descriptive, correlational, and regression analysis to examine the P2P ratio of professional firefighters.

Body Composition: First, using a stadiometer (Detecto, Webb City, MO) and digital scale (BOD POD; Cosmed USA, Concord, CA), bare foot height and body mass were recorded to the nearest 0.01 cm and 0.02 kg, respectively. Body composition (percent body fat, fat mass, and fat-free mass) was estimated using air displacement plethysmography (BOD POD model 2000A; BOD POD; Cosmed USA, Concord, CA) according to standard operating procedures. Thoracic gas volume was estimated, which has been shown to be a valid method when compared to dual x-ray absorptiometry (12). Indexes for body mass (BMI), fat mass (FMI) and fat free mass (FFMI) were calculated as follows: BMI = body mass / height^2 FMI = fat free mass / height^2, and FFMI = fat free mass / height^2.

Bench Press 1RM: To begin, participants completed a supervised and standardized warm-up protocol including a 5-minute light jog followed by 5 minutes of dynamic stretching. Following the warm-up, participants demonstrated the ability to complete the full bench press range of motion from full elbow extension to the bar touching the xiphoid process, using only the barbell. At this time participants began an incremental warm-up based on their self-reported 1RM bench press and according to previously used methods (13,16). The warm-up was as follows: 5 repetitions at 50% 1RM, 1-minute rest, 3-5 repetitions at 60% 1RM, 2-minute rest, 2-3 repetitions at 80% 1RM. Then, 2-minutes of passive rest was allowed prior to attempting single maximal repetitions with progressive incremental loading until the participant experienced a failed attempt, the inability to continue with correct form or the participant stated they did not desire to increase weight after a successful attempt. Rest between the maximal attempts was 2 minutes. Participants were allowed to self-select their grip width and instructed to perform the eccentric motion using a controlled pace, without bouncing the bar off their chest. During all attempts a spotter supervised the participant and provided assistance if needed.

Pull-Up: Maximal effort pull-ups to failure were used to assess posterior (pull) muscular endurance. Participants began by grasping the overhead bar with a pronated grip, slightly shoulder width apart, with full elbow extension, while hanging vertically (feet just above the ground). The pull-up was completed by pulling upright in a linear path until the underside of the chin was level to or above the top surface of the horizontal bar. At which point, the participant descended to the starting position following the same linear and controlled path. Repetitions were not counted if swinging, kicking, or twisting motions were utilized to attempt a repetition or if the participants chin did not at least reach the top of the bar. Participants were required to continuously perform pull-ups and not allowed to rest in the hanging position. The total number of successful repetitions were used for analysis. Estimated pull-up 1RM, used for sP2P, was equal to body mass + 0.033 (body mass x pull-up repetitions) (9,29).

Push-Up: Maximal effort push-ups to failure were used to assess anterior (push) muscular endurance. Participants began in the starting prone position, elbows extended, hands under the shoulders, feet touching the ground, and neutral spine. Participants completed a successful push-up by bending at their elbows until their elbows reached at least 90° (chest approximately ≤ 5 cm from the floor) using a controlled tempo of approximately one second, then returned to starting position. Repetitions were not counted if momentum was used to complete the repetition, the eccentric portion was not controlled, or a straight back was not maintained throughout the repetition. Participants were required to continuously perform push-ups and the attempt was terminated if participants rested for longer than 1 second between repetitions.

Statistical Analysis

Descriptive statistics were computed for all fitness variables and reported as means with 95% confidence intervals. Shapiro-Wilks tests and visual inspection of Q-Q plots were used to examine normality. The following variables did not follow a normal distribution: FFMI, fat free mass, fat mass, Pull-ups, Push-ups and push-up to pull-up ratio. To determine the agreement between sP2P and eP2P a linear regression analysis was performed. Relationships among variables were investigated using Pearson correlation coefficients or Spearman rank correlation coefficients for non-parametric variables, using the following effect size determinants; weak, r = 0.10-0.40; moderate, r = 0.41-0.70; strong, $r \geq 0.71$ (4). Comparison of the relationships were evaluated using Fisher's r to z statistic where appropriate. All statistical procedures were conducted using R, version 3.6.2 (R Core Team, Vienna, Austria; https://www.R-project.org) with an Alpha level of $p < 0.05$.

RESULTS

Table 1. Firefighter descriptive characteristics as mean (95% confidence interval).

	Combined (*N*=33)	Males (*N* = 30)	Females (*N* = 3)
Age, years	36 (21, 50)	36 (22, 50)	30 (22, 38)
Height, cm	177.2 (162.1, 192.4)	178.4 (165.3, 191.5)	165.8 (146.7, 185.0)
Mass, kg	86.46 (57.58, 115.34)	88.69 (62.73, 114.65)	64.10 (43.91, 84.29)
BMI, kg·cm²	27.37 (21.06, 33.69)	27.79 (21.82, 33.76)	23.20 (19.93, 26.47)
Body fat, %	23.53 (10.38, 36.68)	23.64 (10.02, 37.26)	22.37 (14.12, 30.61)
FFMI, kg·cm²	21.34 (15.47, 27.21)	21.31 (16.37, 26.25)	21.60 (7.56, 35.63)
FMI, kg·cm²	6.60 (2.32, 10.88)	6.74 (2.38, 11.09)	5.22 (2.75, 7.70)
Bench 1RM, kg	91.97 (43.66, 140.28)	95.87 (52.35, 139.40)	52.92 (38.63, 67.21)
Pull-up 1RM, kg	109.45 (69.66, 149.24)	113.21 (17.08, 146.69)	71.78 (4.61, 80.81)
sP2P	0.84 (0.57, 1.10)	0.85 (0.14, 1.11)	0.74 (0.06, 0.85)
Push-ups, repetitions	33.82 (10.12, 57.52)	34.70 (10.91, 58.49)	25.00 (8.03, 41.97)
Pull-ups, repetitions	8.30 (-2.18, 18.78)	8.73 (-1.74, 19.21)	4.00 (-3.07, 11.07)
eP2P	6.77 (-6.81, 20.35)	6.15 (-5.20, 17.50)	12.92 (-16.11, 41.94)

Abbreviations: BMI, Body Mass Index; FFMI, Fat Free Mass Index; FM, Fat Mass; 1RM, one repetition maximum; sP2P, strength Push to Pull Ratio of bench press 1RM divided by estimated pull-up 1RM; eP2P, endurance push to pull ratio of push-up repetitions divided by pull-up repetitions.

Descriptive characteristics, body composition and performances on upper body fitness assessments are presented in Table 1. The linear regression results noted no association between sP2P and eP2P ($R^2 = 0.032$, $p = 0.99$). Strength P2P Push to pull ratios had a strong relationship with bench press 1RM and weak relationship with push-ups (Table 2). Endurance P2P had moderate negative correlation with pull-up repetitions and weak positive correlations with body fat percentage and fat mass index (Table 2).

Table 2. Intercorrelation matrix of variables.

	BF%	BMI	FFMI	FMI	Push-up	Pull-up	eP2P	Bench 1RM	Pull-up 1RM	sP2P
sP2P	-0.12	0.16	0.03	-0.07	0.40*	0.20	0.00	0.80*	0.17	-
Pull-up 1RM	-0.17	0.60*	0.43*	0.08	0.35*	0.49*	-0.37*	0.72	-	
Bench 1RM	-0.19	0.46*	0.30	-0.01	0.44*	0.44*	-0.26	-		
eP2P	0.40*	0.11	-0.23	0.34*	-0.20	-0.62*	-			
Pull-ups	-0.68*	-0.27	0.24	-0.59*	0.71*	-				
Push-ups	-0.42*	-0.10	0.00	-0.39*	-					
FMI	0.94*	0.72*	-0.14	-						
FFMI	-0.39*	0.31	-							
BMI	0.51*	-								
BF%	-									

Notes: *, indicates significance at $p < 0.05$. Abbreviations: BF%, body fat percentage; BMI, Body Mass Index; FFMI, Fat Free Mass Index; FM, Fat Mass; 1RM, one repetition maximum; sP2P, strength Push to Pull Ratio of bench press 1RM divided by estimated pull-up 1RM; eP2P, endurance push to pull ratio of push-up repetitions divided by pull-up repetitions.

DISCUSSION

The aims of the current study were to investigate the association between sP2P and eP2P and evaluate relationships of potential factors contributing to sP2P and eP2P. Previous literature (1,20) has suggested that the P2P absolute strength ratio should be approximately 1.00, which would propose that the same amount of mass can be lifted in the push and pull movements. For the firefighters in the current study the sP2P was below the recommended ratio of 1.00 with an average sP2P of 0.84. These findings are similar to prior sP2P of 0.89 when collegiate wrestlers performed machine bench press and row 1RMs (3). Although some form of row may provide a more direct antagonist comparison to the bench press 1RM, the pull-ups are a common test to be performed in firefighters (25). However, when evaluating sP2P in similar planes of movement of the current study, rugby players had a P2P of 0.97 when performing 1RM free weight bench press and weighted pull-ups (1). One possible explanation for the differences in sP2P, despite similar movements, is that the current study evaluated estimated pull-up 1RM, not actual. Although pull-ups for repetitions is a more practical and common assessment in firefighters than a pull-up 1-RM, it is possible that the pull-up 1RM may be overestimated for those that performed many pull-up repetitions (21). When assessing repetitions to failure on both the pull-ups and push-ups, the firefighters in the current study had an eP2P of 6.77. This ratio is much higher compared to the sP2P in the current study, as well as prior findings of endurance P2P of 1.6 to 2.7 when using repetitions performed in timed push-up and inverted rows by strength trained males and females (18). After comparing the sP2P to the eP2P in the current study, it may be reasonable to suggest that the lower sP2P may be a result of low maximal pushing strength while the much higher eP2P may be a result of focused efforts on pushing muscle endurance and potential neglection of pulling muscle fitness. Thus, improving maximal pushing and pulling capabilities may both benefit firefighters to result in balanced muscular performance around the joint, but suggestions on improving pushing versus pulling fitness may be dependent on whether sP2P or eP2P is being evaluated. Therefore, we suggest eP2P and sP2P ratios may be beneficial to assess in addition to the absolute and relative interpretations of upper body fitness scores.

When interpreting the P2P ratio that incorporates a bodyweight push-up assessment it should be noted that the pull-up requires the participant to lift 100% of their bodyweight; whereas the push-up would require approximately 64% to 75% of bodyweight to be lifted (7,26). Assuming that approximately two-thirds of bodyweight is required to be lifted during a push-up in order for an equal balance of pushing to pulling one would be expected to perform 1/3 fewer pull-ups or have a P2P ratio of 1.5 (1 divided by 0.67). Thus, key factors to consider when interpreting the P2P ratio are load lifted (1RM effort vs repetitions to failure) and the plane of motion (horizontal vs. vertical). Accordingly, when comparing the results of the current study to prior literature it is somewhat difficult due to the varying protocols used. Yet, these findings should be taken with caution and future research is warranted to confirm these results using actual pull-up 1RM and/ or a horizontal pulling test. Further, in consideration of the aforementioned and the lack of association between sP2P and eP2P, it is important to note that P2P should not be used interchangeably if calculated using different protocols.

Since firefighters perform occupational tasks that require forceful pushing or pulling it could be suggested to monitor strength development in both actions. However, some have found pull-up performances to be a high priority considering its impact on occupational specific testing in tactical populations, such as body drag and wall or fence climbing assessments (11). Additionally, previous literature has reported that upper body pushing and pulling is important for firefighters to perform many occupational tasks (15,22). Aside from the importance of upper body strength in occupational tasks, the current study highlights the importance of anterior and posterior muscle strength as it relates to imbalances in sP2P and eP2P, respectively. This is supported by the moderate relationship of pull-up performances to eP2P, which were greater than push-ups ($Z = 2.02$, $p = 0.04$). Moreover, a large percentage of firefighters were not capable of performing a single pull-up. However, when comparing relationships to sP2P, bench press 1RM was more related to sP2P than estimated pull-ups 1RM ($Z = 3.59$, $p < 0.001$). Thus, providing further support of our notion that firefighters may need to train maximal effort pushing and pulling abilities. Additionally, eP2P, as well as push-ups and pull-ups, were related with fat mass. Previous literature supports this notion that body fatness is negatively related to performance of occupational tasks in firefighters, as well as law enforcement officers (14,28). However, body mass index may not be an indicator of performance capabilities of movements requiring manipulating one's own body mass, but may relate to one's maximal strength capabilities, as seen in prior research (6). Collectively, both fitness capabilities and body fatness are important factors for creating a balance of strength in anterior and posterior shoulder musculature. However, indication of whether anterior or posterior musculature is lacking may be dependent on the type of P2P ratio being evaluated.

Limitations of this study must be considered. To start, the push-up requires lifting approximately 64-75% of their body mass (7,26) compared to 100% body mass lifted during the pull-up. Another limitation is the variation of training statuses of participants. Although, all reported current participation in regular physical activity, there was no report of length in history of physical training or intensity of current training programs. Yet, previous training history (i.e. endurance or strength focused) may influence the number of repetitions one is able to perform for a given exercise, which may have played a role in the differences between eP2P and sP2P scoring (23). Lastly, the pull-up test, although common for firefighter fitness assessments, may be more reflective of muscular strength or endurance depending on the individual's capabilities. Thus, a comparison was made between sP2P and eP2P, to begin understanding the balance of pull-up performances compared to strength and endurance pushing assessments and which may need more priority in training. However, directly testing maximal strength and muscle endurance is encouraged, specifically in the same plane of motion, to truly understand the muscle balance in this population. Future studies should consider the aforementioned limitations and attempt training interventions to improve P2P as well as investigating the relevance of P2P as an injury screening mechanism.

In conclusion, for firefighters the average sP2P appears to be lower than the eP2P with a high percentage of firefighters being incapable of performing at least one pull-up. This may suggest a need for implementing assessment and training strategies for improving maximal pushing and pulling performances. Another factor influencing pull-up, push-up, and eP2P performances was body fatness. Thus, it would be beneficial to implement strategies to combat high levels of body fatness in firefighters. This may help with improving absolute upper body muscular fitness capabilities and balance among upper body shoulder musculature. Lastly, it does not appear the P2P from strength and endurance assessments can be used interchangeably. Practitioners are encouraged to consider the novel sP2P, eP2P along with traditional measures of absolute strength, relative strength and body fatness when interpreting upper body muscular fitness assessment data of firefighters.

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