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Functional Movement Screen and Y-Balance Test Scores, With Personal Protective Equipment Among Wildland Firefighters: Pilot Findings

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ABSTRACT

Purpose: Wildland firefighting is a dangerous profession and maintaining adequate strength and balance is essential in injury reduction. However, the impact of personal protective equipment (PPE) on injury risk is not well understood. The Functional Movement Screen (FMS) and the Y-Balance Test (YBT) are intended to identify movement limitations but have only minimally been examined among wildland firefighters (WLFF) utilizing PPE. The purpose is to determine if PPE affects FMS and YBT scores among WLFF. **Methods:** A randomized crossover study of ten well-trained, experienced WLFF employed and physically qualified for deployment was conducted testing FMS and YBT outcomes with and without PPE. **Results:** Significant differences were found in the YBT right and left lower body composite scores (RLQ CS and LLQ CS respectively), $p = .005$ for both, right and left anterior reach ($p = 0.001$ and $p < 0.05$ respectively), right and left posterior medial reach ($p = 0.005$ and $p = 0.009$ respectively), and in left posterior lateral reach ($p = 0.047$). **Conclusions:** These preliminary findings suggest the use of PPE negatively impacts scores and might increase the risk of injury for WLFF. This information may be useful in developing injury prevention programs for this and other PPE wearing populations.

KEYWORDS: Injury screening, injury prevention, lower extremity, upper extremity, limb asymmetries, tactical athlete.

Introduction

Wildland firefighting is a dangerous occupation with a variety of risks and hazards encountered on a daily basis while performing the duties involved in the profession[1–6]. Currently, and for a variety of reasons, there is limited information within the literature regarding the types and

prevalence of injuries sustained by wildland firefighters (WLFF) in the course of performing their duties in the field[1,3,7]. Of particular interest in this study are musculoskeletal injuries commonly sustained by this population. Hoffman and colleagues[7] in a web-based survey noted 40% of WLFF reported having sustained some kind of injury. As part of a broader project in 2015, Mangan[8] conducted an online survey in which 46% of respondents (485 of 1058) self-reported having sustained an injury during physical training activities while on the fire line. Within Spanish WLFF, Garcia-Haras et al.[9] found half of their reported injuries were to the lower extremity. Kuehl et al.[10] reported that among 433 WLFF, 160 (37%) participants sustained 184 (42%) injuries with strains and sprains being the most commonly reported accounting for 48% of the injuries. In their study, the back was the most often injured and accounted for 35% of reported injuries followed by the knee and lower leg, which accounted for 17% of all injuries. These findings were similar to those observed by Moody et al.[5] where they found half of all injuries reported were sprains and strains to the lower back, knee, and ankle. Britton et al.[2] utilized non-fatal injury data from the 2003-2007 fire seasons to evaluate the number, type, body part, and mechanism of injury. They identified a total of 1,301 injuries reported with the most common mechanism of injury being slips, trips, and falls (28%) accounting for 35% of all lower body injuries, making up 49% of sprains and strains, and 43% of fractures and dislocations. In 2017, Purchio[6] used a web-based, cross-sectional questionnaire and noted that of the 453 injuries identified, 85% occurred on the fire-line with slips, trips, and falls accounting for 29.9% of injuries. The most prevalent of these injuries affected the low back (15.9%), hip/thigh (2.9%,), knees and lower leg/ankles (17.2%), and foot and toes (6%). Given the inherent danger of wildland firefighting and the high incidence of slips, trips, and falls, it is critical to identify the factors that may contribute to these events, including the environment, terrain, fatigue and stress. Each of which may alter musculoskeletal movement patterns and impair balance, thereby increasing injury risk. Of equal importance for this population is to determine what role, if any, the use of PPE may play in the occurrence of slips, trips and falls and by extension, fire line injuries.

The Functional Movement Screen (FMS) has been incorporated into a variety of athletic/performance populations and settings and can assist identification of movement limitations, asymmetries, and pain associated with movement patterns[11,12]. Some preliminary studies have reported that the FMS may have a predictive value for future injuries on a variety of populations, including firefighters[8,13–16], while others show no or limited benefit and suggest further research is warranted[17–19]. Another tool being utilized to evaluate dynamic upper and lower body balance and motor control is the Y-Balance Test (YBT). Like the FMS, it is designed to determine deficits and asymmetries in both the upper

and lower extremity. While some research has questioned the accuracy of the injury prediction value of the YBT[20,21], others have found it to be a useful tool[22,23].

Healthcare providers administering injury screening to WLFF typically do so using standard testing protocols without the use of PPE. However, since tasks on the fire line require individuals to wear specialized safety equipment, the use of PPE during injury screening should be implemented to enhance testing protocols. The variable of PPE on tactical athletes has had minimal consideration to the physical demands of their occupational tasks. Therefore, it is of interest to determine if inclusion of PPE during FMS and YBT provides ecological validity to the physical demands of WLFF. Overall, improved identification of individuals with musculoskeletal injury risk as identified by the FMS and YBT with the use of PPE can advance injury mitigation strategies in various rural firefighting settings.

Taking into consideration the data regarding musculoskeletal injury among WLFF, there is a need to establish appropriate testing modalities to predict commonly reported injuries and, if possible, implement proactive approaches to injury mitigation. Therefore, our aim in this pilot study was to determine if personal protective equipment (PPE) affects performance on functional movements and mobility in WLFF. We hypothesize that PPE would negatively influence YBT and FMS scores.

Methods

Participants

Following approval from the University Institutional Review Board, ten well-trained adults, employed as WLFF with the local Bureau of Land Management and physically qualified for deployment, were recruited to participate in this study. Inclusion criteria consisted of those "Ready to Deploy," which was operationally defined as "Individuals available to be called to an active fire scene with no limitations for deployment." Exclusion criteria consisted of anyone not considered "Ready to Deploy." We pre-screened participants for eligibility via fire station eligibility list, clearly explained study procedures, and answered questions prior to obtaining voluntary, written informed consent for participation.

Baseline Measurements

Upon enrollment, years of firefighting experience was documented. Then, the same well-trained lead investigator recorded all baseline anthropometric and physiological measurements including height, body mass, body mass index (BMI), seated heart rate (HR), seated blood pressure (BP), 7-site skinfold assessment, and handgrip strength. We measured body mass to the nearest 0.5 kg on a medical grade scale, and height to the nearest 0.5 cm using a stadiometer. BMI was calculated as $\frac{\text{body mass (kg)}}{[\text{height (m)}]^2}$. We obtained seated HR and BP using an automated analyzer (e-sphyy3 Digital Blood Pressure Monitor, American Diagnostic Corporation, Hauppauge, NY, USA). After participants sat quietly for 5

minutes in a chair with back support, legs uncrossed with feet on the floor, and arms supported at near heart level. Finally, we obtained duplicate measures of the left arm brachial artery systolic and diastolic blood pressure (BP), separated by at least 1-min, and averaged.

Skinfold Measurements

Using a Lange skinfold caliper, we measured skinfold sites on each participant using standardized protocols and procedures. With the individual standing upright, we took measurements on the right side of the body at the midaxillary, chest/pectoris, abdomen, subscapula, suprailiac, triceps, and thigh. Each site was measured three times, and we recorded the average of the three values. The Jackson-Pollock 7-site skinfold equation was used to calculate body density and the Siri equation was used to convert body density to body fat percentage.

Hand Grip Strength

While seated in an upright position, with the arm at a right angle and the elbow by the side of the body, we handed the participant a dynamometer, with the base resting on the first metacarpal and the handle resting on the middle of the four fingers. We tested the dominant prior to the non-dominant hand and instructed the participant to squeeze the dynamometer with maximum isometric effort, which was maintained for approximately 5 seconds. No other body movements were allowed during the testing procedure and the participant transitioned from the dominant to non-dominant hand 3 times with 30 seconds rest between each attempt. We collected data from the 3 attempts from each hand and documented the average for both left and right.

FMS and YBT Testing Protocols

All testing and pre-test assessments were performed by the same individuals certified in both FMS and YBT test procedures. We encouraged participants to wear appropriate fitness attire (i.e. workout shoes, shorts, and t-shirt), for completing the control protocol, and PPE (i.e. protective outerwear, boots, helmets and gloves) for the experimental condition. Prior to testing we explained, demonstrated, and allowed participants to practice the movement before beginning. Participants performed two FMS assessments, one FMS control and one FMS experimental condition, and two YBT protocols, a YBT-Lower Quadrant and a YBT-Upper Quadrant, each with a control and experimental condition. We randomly assigned the initial test (FMS or YBT) and condition (PPE or No PPE), followed by the second test with the same condition. The third test was the same test as the second test with the opposite condition, followed by the fourth and final test. For example, if the initial random assignment was the FMS with PPE, the second test administered was the YBT with PPE, followed by the YBT with no PPE and FMS with no PPE. Participants performed four total assessments in one visit. We utilized this method of randomization for the purposes of saving time by not having individuals change in and out of PPE repeatedly. The goal of the FMS is

Table 1: Descriptive characteristics and demographics of population

Parameter	Mean ± SD	Range
Age (y) (n=10)	35.1 ± 8.7	25.0-52.0
Height (cm)	175.3 ± 7.5	161.3-186.7
Mass (kg)	87.1 ± 12.9	62.7-103.6
BMI	28.3 ± 3.6	24.0-35.0
Body Fat. (%)	17.2 ± 5.7	7.8-26.9
Experience as a Wildland Firefighter (y)	12.1 ± 8.0	4.0-30.0
Seated Heart Rate ($b \cdot min^{-1}$)	74.2 ± 11.6	61.0-100.0
Seated Systolic Blood Pressure (mmHg)	134.2 ± 13.2	118.0-163.0
Seated Diastolic Blood Pressure (mmHg)	80.1 ± 11.6	62.0-98.0
Grip Strength – Right (kg)	56.0 ± 7.4	47.0-67.0
Grip Strength – Left (kg)	55.8 ± 6.8	46.0-68.0

Table 2: Y-balance test outcomes

Quarter	Direction	Extremity	Without PPE	With PPE
Lower	Anterior	Left	67.9 ± 11.6[a]*	63.7 ± 14.0
		Right	69.3 ± 10.6*	63.3 ± 11.5
	Posteromedial	Left	107.7 ± 6.0*	101.1 ± 7.7
		Right	108.6 ± 7.3*	102.7 ± 6.6
	Posterolateral	Left	115.1 ± 4.7*	112.0 ± 5.4
		Right	113.6 ± 5.4	111.3 ± 6.4
	Composite	Left	104.7 ± 10.1*	99.7 ± 11.4
		Right	105.0 ± 9.9*	99.9 ± 11.0
Upper	Medial	Left	80.5 ± 29.1	81.6 ± 29.2
		Right	91.6 ± 6.8	90.2 ± 7.3
	Inferolateral	Left	72.7 ± 29.8	78.7 ± 29.4
		Right	86.5 ± 14.7	86.7 ± 8.5
	Superolateral	Left	62.8 ± 25.0	58.3 ± 23.9
		Right	63.7 ± 15.5	66.3 ± 16.1
	Composite	Left	80.6 ± 30.6	81.5 ± 30.6
		Right	90.2 ± 14.9	90.7 ± 12.4

Values are reported as [a]mean ± SD. PPE, personal protective equipment.
*p≤0.05 between group difference

to identify movement limitations and asymmetries within seven movement tests: deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability. Each test was scored on a 0 to 3 scale with a 3 indicative of a correct, pain free movement without compensation, 2 indicating a movement that requires compensation, 1 indicating an incomplete movement, and a score of 0 is given if a movement elicits pain. With these parameters, a maximum FMS score of 21 could be achieved. We had participants perform the FMS both with and

without PPE. The YBT-lower quadrant and a YBT-upper quadrant assessments both incorporate three movement directions. The lower quadrant utilizes an anterior, posteromedial, and posterolateral movement pattern and the upper quadrant utilizes a medial, inferolateral, and superolateral pattern. The goal of the YBT-lower quadrant assessment is to maintain a single-leg stance on one leg while reaching as far as possible with the contralateral leg. The goal of the YBT-upper quadrant assessment is to maintain a pushup position while on the center platform of the YBT device and push the reach indicator with one hand as far medially and diagonally across the body in the inferolateral and superolateral directions. In scoring the YBT-lower quadrant we first measured leg length from the anterior superior iliac spine to the medial malleolus in cm and then measuring the arm length in cm from the C-7 spinous process to the tip of the longest digit with the arm in 90 degrees of abduction. Scoring the upper and lower quadrants were similar. First, we documented the maximum reach in each of the three directions. Next, we normalized the scores by taking the maximum reach distance in each direction and dividing that by the individual's leg or arm length for lower and upper body, respectively, and multiplying that result by 100. The formula is as follows: Normalized reach (%) = [reach distance (cm) / limb length (cm)] x 100. And finally, we calculated the composite score by adding the sum of each of the three normalized scores for one leg or arm and dividing that sum by three times the leg or arm length, respectively, and then multiplied by 100. The formula is as follows: Composite score (%) = [sum of all 3 reach directions (cm) / 3 x limb length (cm)] x 100.

Table 3: Functional movement screening composite scores and total scores

	Without PPE					With PPE				
	Composite Score Frequency					Composite Score Frequency				
FMS Test	**0**	**1**	**2**	**3**	**Mean ± SD**	**0**	**1**	**2**	**3**	**Mean ± SD**
Deep Squat	0	0	7	3	2.3 ± 0.5[a]	0	0	8	2	2.2 ± 0.4
Hurdle Step	0	0	6	3	2.4 ± 0.5	0	1	5	4	2.3 ± 0.7
Inline Lunge	0	0	4	4	2.6 ± 0.5	0	0	5	5	2.5 ± 0.5
Shoulder Mobility	0	1	5	6	2.3 ± 0.7	1	1	4	4	2.1 ± 1.0
Active Straight Leg Raise	0	5	3	4	1.7 ± 0.8	0	5	3	2	1.7 ± 0.8
Trunk Stability Pushup	0	0	2	2	2.8 ± 0.4	0	0	1	9	2.9 ± 0.3
Rotary Stability	1	2	7	8	1.6 ± 0.7	1	3	5	1	1.6 ± 0.8
Total Score					15.7 ± 2.1					15.3 ± 2.6

Values are reported as [a]mean ± standard deviation. FMS, Functional Movement Screen; PPE, personal protective equipment.

Statistical Analysis

We performed all analyses using IBM SPSS Version 29.0 (IBM Corporation, New York, NY, USA). Descriptive statistics are reported as mean ± standard deviation. Data were analyzed using a Wilcoxon Signed Rank Sum Test to compare FMS and YBT individual and composite scores between conditions. Significance level was set at $p = 0.05$.

Results

Nine males and one female (Table 1) completed all testing protocols (age, 35.1 ± 8.7 y; height, 175.3 ± 7.5 cm; mass, 87.1 ± 12.9 kg; BMI, 28.3 ± 3.6 kg·m^2, body fat percentage, 17.2 ± 5.7%), and 12.1 ± 8.0 years of firefighting experience. Participants had a right grip strength of 56 ± 7.4 kg and a left grip strength 55±6.6 kg.

We found significant differences in the YBT right lower quadrant composite scores and left lower quadrant composite scores, both lower with PPE compared to without ($p = 0.005$ for both). We did not identify any significant findings in the right or left upper quadrant composite scores. When looking at the individual components of the lower quadrant YBT scores, we found significant differences in the right and left anterior reach ($p = 0.001$ and $p < 0.05$ respectively), right and left posterior medial), reach ($p = 0.005$ and $p = 0.009$ respectively), and in the left posterior lateral, reach ($p = 0.047$), all of which were lower (worse) with PPE vs without (Table 2). We found no significant differences with FMS composite score frequencies between conditions. Overall frequency scores for each test parameter for the FMS testing are shown in Table 3.

Discussion

Though significant findings were noted in the right and left YBT lower quadrant composite scores and all but one of the individual scores (right posterior lateral reach). We found that no participants in the condition without PPE and only one participant in the condition with PPE achieved lower quadrant composite scores <89%. Only one participant had a lower quadrant asymmetry > 4 cm in the condition without PPE. These values have been identified as the cut off point for injury prediction[21,23,24]. However, when donning PPE, lower quadrant asymmetries > 4 cm in our participants increased upwards of 30% among 4 participants, indicating a potential for higher risk of injury while using PPE. Similar findings were noted in research conducted by Moody et al.[25] investigating active duty Smoke Jumpers utilizing the FMS overhead squat and hurdle step as well as the YBT anterior reach in a controlled non-weighted condition and an experimental weighted condition which added a 22.7 kg pack. They reported significantly lower scores in all loaded (with pack) conditions as compared to unloaded (without pack) conditions, except for the anterior reach. Of note is that the standard YBT-lower quadrant protocol used in the Moody et al.[25] study had a barefoot procedure, footwear during the FMS was not standardized, and only the weighted pack was incorporated as PPE. Our study utilized the participant's

choice of training shoes for the control condition and certified WLFF boots for the experimental condition for both the FMS and YBT testing procedure and we did not add the pack to the PPE. The use of varied footwear and the lack of a weighted pack in our study could account for the differences noted in the anterior reach component of the YBT. Thus, though both studies suggest that PPE may have a negative impact on components of FMS and YBT scores, future research should consider standardized testing parameters on this population.

Limitations and Future Directions

This study identified multiple methodological limitations, including small sample size, only one female participant, and difficulty visually identifying bony landmarks on participants, especially when attempting to accurately administer and score FMS testing on the WLFF population that required PPE covering the body. If these tests are to be utilized to determine if PPE affects scores in a negative manner, future researchers might consider altering the protocol of these tests for this, and similar populations, to include wearing approved footwear, which tend to have an elevated heel of varying heights, upwards of 3 inches were noted in our study. This height alters both the tibial measurements for the FMS and the leg length measurement of the YBT between control and experimental conditions, so individual measurements and calculations would need to be taken during each condition. The increased heel height also may assist in increasing the depth of the overhead squad utilized in FMS allowing for higher scores to be achieved as compared to a barefoot protocol. Further protocol considerations for the WLFF population might be to incorporate the weighted pack within the intervention group and perhaps streamline the testing procedures by eliminating the upper extremity component of the YBT and focus on the functional components of the FMS, which includes the inline lunge, hurdle step, and deep squat, similar to the Moody and colleagues[25] study previously mentioned.

Conclusion

These preliminary findings suggest that if the FMS and YBT are to be used in an injury prediction capacity for this population, there is a need for a larger investigation aiming to further refine test administration to account for PPE among WLFF and similar tactical athletes. Further, health care providers and strength and conditioning specialists aiming to reduce musculoskeletal injuries in WLFF or other tactical populations may consider donning PPE during at least some time during the training process to replicate physical stresses required equipment place on the individual during occupational tasks, in essence, creating a type of “sport specificity” to the training routine.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflict of interest.

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