



## **Triple Hop for Distance as a Predictor of Lower Extremity Performance in Firefighter Equipment**

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### ABSTRACT

*International Journal of Exercise Science* 12(6): 515-525, 2019. The objective of this study was to examine the predictive value of the Triple Hop for Distance (THD) physical performance test to assess lower extremity (LE) strength and power in individuals donning firefighter personal protective equipment (PPE). Thirty-one healthy participants completed the THD in firefighter PPE on both the dominant and non-dominant limb. Dependent variables included LE power (vertical jump height [cm]) on a jump mat, and LE strength of the quadriceps and hamstrings (peak torque [Nm]) on an isokinetic dynamometer. THD was a strong predictor of LE power on the dominant ( $p < 0.01$ ) and non-dominant ( $p < 0.01$ ) limbs. THD was also a moderate predictor of LE strength on both the dominant limb (Ham60 [ $p < 0.01$ ]), Quad60 [ $p < 0.01$ ]), and the non-dominant limb (Ham60 [ $p < 0.01$ ]), (Quad60 [ $p < 0.01$ ]). The THD was found to be a strong and valid predictor for clinical measures of LE power and strength in firefighter PPE.

**KEY WORDS:** Tactical athlete, health and safety, athletic training, healthcare, outcome measures

### INTRODUCTION

According to census data reported by the National Fire Protection Association (NFPA) in 2015, there are an estimated 1,160,450 career and volunteer firefighters working in the United States (13). Firefighters are exposed to high levels of occupational risk that predispose them to injury, illness, and potentially death (22). Firefighters often operate in unpredictable situations while managing physical hazards including extreme heat, disorienting noises, and unstable environments (12, 31, 32). To mitigate the occupational risk associated with structural firefighting, advanced fire retardant personal protective equipment (PPE) has been adopted by firefighters for use at the fire ground (7). The engineering advancements in PPE for firefighters developed over time have decreased injuries due to the fire hazards like flames and smoke (4).

The standard issue structural firefighter PPE includes a hard shell helmet, pants, jacket, facemask, oxygen tank, rubberized boots, and a fire resistant hood (4, 17). Together the mass of the ensemble is approximately 21.2kgs with the oxygen tank, or approximately 11.1kg without the oxygen tank (17, 24). This increased external mass places an additional physiologic burden on firefighters (32). The mass of the equipment paired with long-term use has been attributed to increased oxygen demands, reduction in exercise tolerance, increased metabolic demands, and a decrease in overall physiological function in fire ground operations (32).

Firefighters are at an increased risk for musculoskeletal injury due to gait alterations, postural control deficits, and exertional fatigue attributed to the use of PPE (16, 23, 29). While mitigating inherent occupational risks, PPE also has the potential to predispose firefighters to an increased risk of acute and chronic musculoskeletal injuries due to increased load carriage, proprioceptive changes, and increased physiological burden (17, 29, 32). In 2014, the NFPA reported an estimated 68,085 non-fatal injuries had occurred on the job site with musculoskeletal injuries, such as sprains, strains and muscular pain, accounting for 52.7%, or 35,880, of the total injuries (12). Lower extremity injuries were the most prevalent in firefighters according to the NFPA, comprising of 22% of the total non-fatal 68,085 injuries experienced in 2014 (12).

With the requirement of PPE limiting the function and mobility of firefighters, there is a need to understand the effect that such equipment has on their physical performance. Furthermore, previous literature has also concluded that firefighters with a higher comprehensive fitness status had a significant reduction in injury risk compared to those who had a lower comprehensive fitness status when completing job specific tasks (26). Firefighters are screened during basic fire training to ensure they have a high level of physical fitness to complete job specific tasks efficiently and effectively. The Candidate Physical Ability Test (CPAT) is an assessment used to determine fire recruit proficiency in completing eight job specific tasks including a stair climb, search, equipment carry, and rescue (36). During the CPAT recruits wear a 50lb weight vest to simulate the firefighter specific PPE that is worn in the fire ground (26). Despite the CPAT being required for recruits prior to entering the fire service, only an estimated 30% of fire departments nationwide require ongoing physical performance assessments similar to the CPAT to determine ongoing physical ability and performance (28).

Previous literature supports the measures of general strength and endurance as a predictor of firefighter performance on job specific tasks such as the hose drag and rescue carry which highlights the importance of the CPAT (14, 26, 30). As such, there is a need for ongoing physical performance testing in structural firefighters to identify and address musculoskeletal deficiencies that may predispose them to injury in the fire ground. The connection between task performance and physical testing is vital to ensure the efficiency and safety in the work environment (5, 34).

As a result, there is a need to identify physical performance tests that may be used with tactical athlete populations to identify deficiencies that predispose the individual to injury. One such physical performance test is the Triple Hop for Distance (THD). The THD tasks the individual with completing three consecutive single-leg hops for maximal horizontal distance while landing on the same leg (11). The measure for the THD is completed after the third hop (11). Previous research has identified an ICC of 0.95 for this tool when used on asymptomatic young

adults (3). Traditionally, the THD measures are used to determine clinical measures of leg symmetry index for anterior cruciate ligament reconstruction (25). However previous research has also identified the THD as a valid predictor of lower extremity (LE) strength and power, supporting its use as a screening tool in a young, healthy population (11, 27). The increased load, which firefighters wear in the form of PPE, may change the predictive values of the test. Therefore, the purpose of this exploratory study was to investigate the predictive value of the THD for LE strength and power in recreationally active non-firefighters donning firefighter PPE for the first time, simulating untrained individuals entering a fire academy.

## METHODS

### *Participants*

Thirty-one healthy participants (sex: male = 20, female = 11; age =  $23.32 \pm 2.81$ y; height =  $175.30 \pm 11.12$ cm; mass =  $77.94 \pm 14.24$ kg; mass in PPE =  $89.14 \pm 14.68$ kg; leg dominance: right limb = 29, left limb = 2) with no reported chronic health conditions or LE injuries within the last six months volunteered. All participants self-reported as physically active, participating in more than 200 minutes per week of exercise or exercise related activities. None of the participants reported any experience or formal training as a firefighter. This study was approved by the Institutional Review Board at Indiana State University, and conformed to the latest revision of the set forth standards of the Declaration of Helsinki. Prior to the study, each participant was informed of study specifics and provided written informed consent.

### *Protocol*

The protocol developed for this study was based on the procedures utilized by Hamilton et al.(11) to validate the THD for use as a unilateral assessment and predictor of LE strength and power in a healthy population. The primary investigator conducted all data collection sessions with participants and was the sole individual instructing participants and recording measurements. Once participants provided informed consent, basic anthropometric and demographic data were collected including age, sex, height, and weight. Prior to data collection, limb dominance was determined by utilizing the Functional Leg Dominance (FLD) assessment described in previous research (15). Data were recorded on THD scores (cm), vertical jump (VJ) height (cm), and isokinetic peak torque (Nm) for concentric knee extension (Quad<sub>60</sub>, Quad<sub>180</sub>) and concentric knee flexion (Ham<sub>60</sub>, Ham<sub>180</sub>) at the angular velocity of 60°/sec and 180°/sec. The order of testing was determined for each dependent variable using the block randomization method. Data collection on each dependent variable occurred over the course of two sessions, with a minimum of 48 hours separating each session.

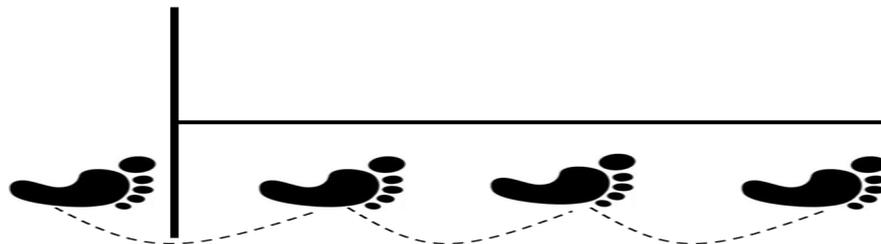


Figure 1: Visual Representation of the Triple Hop for Distance Test

Triple Hop for Distance: THD testing occurred during the first data collection session after FLD was assessed. A visual representation of the test is available in Figure 1.

Participants were allowed a five-minute self-directed bike warm-up prior to data collection. To account for learned effect and fatigue in data collection, we used block randomization to determine whether the dominant or non-dominant limb was tested first in the THD. Participants were required to complete a minimum of 1 practice trial prior to each recorded THD trial on both the dominant and non-dominant limb to familiarize themselves with the THD in firefighter PPE. Participants were allowed 2 additional optional practice trails on each limb prior to the recorded trial if they desired, for a maximum of 3 practice trials. The use of the required and optional practice trails to familiarize participants with the THD is consistent with previous literature (11). Participants were allowed to determine when, and for how long, they took rest intervals in-between each recorded trial of the THD as needed to prevent fatigue. We measured the distance from the start marker to the heel of the participant's foot at the conclusion of the final hop. Unsuccessful attempts were recorded if the participant 1) did not complete the trial as instructed, 2) lost balance during any portion of the test, or 3) could not hold the final stance on a single limb for at least two seconds. We placed no cap on the number of unsuccessful attempts, and provided a brief statement as to why the trial was considered an unsuccessful attempt for educational purposes. The first three acceptable trials were recorded, and the mean distances of successful trials were taken for data analysis.

Isokinetic Dynamometry: We utilized an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) to assess peak concentric torque of Quad<sub>60</sub>, Quad<sub>180</sub>, Ham<sub>60</sub>, and Ham<sub>180</sub>. Participants were asked to complete a five-minute self-guided bike warm up prior to isokinetic testing. At the conclusion of the warm up, block randomization was utilized to determine which of the participant's limbs would be tested first on the dynamometer. Once participants were seated in the dynamometer, a familiarization protocol was administered prior to the collection of data for each trail (Quad<sub>60</sub>, Quad<sub>180</sub>, Ham<sub>60</sub>, and Ham<sub>180</sub>). This familiarization protocol consisted of four consecutive repetitions of knee flexion or extension at increasing intervals of 25%, 50%, 75%, and 100% effort at the angular velocity of the proceeding trial. Participants were given a two-minute rest intervals, consistent with the literature, between the familiarization protocol and recorded trial to allow for recovery prior to data collection (10, 33). Data extraction was completed using the full report function from the Biodex System for each dependent variable on the dominant and non-dominant limb. The research team provided verbal encouragement to the participant throughout the isokinetic dynamometer testing.

Vertical Jump: We utilized a vertical jump mat (Just Jump, Probotics, Inc., Huntsville, AL) to assess maximum VJ height calculated by jump flight time. Jump mats have been validated as a measurement of LE peak power using hang time algorithm to calculate VJ height (20, 35). VJ height was assessed after the participants had completed isokinetic testing. Participants had a five-minute washout period after the completion of isokinetic dynamometer testing to reduce the effect of fatigue on VJ results. No warm up was needed given the intensity of the isokinetic testing prior to VJ assessment. Instructions were given to the participant to stand on the mat and perform a maximum effort VJ, landing with both feet on the jump mat. A countermovement

jump method was utilized to assess VJ based on the technique described in previous literature (21). Three trials were allotted, and participants were allowed to determine when, and for how long, intervals were taken. A scratch was recorded if the participant did not land squarely on the jump mat, and the participant was instructed to repeat the trial. The mat was connected to a handheld computer that displayed the hang time and jump height. Maximum jump height was used for VJ scores, consistent with the original study validating the THD for use in healthy populations.(11)

### Statistical Analysis

Data was transferred into a custom spreadsheet (Microsoft Excel 2010, Microsoft Corp., Redmond, WA) and analyzed using the Statistical Package for Social Sciences version 23 (IBM Corp. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY) Descriptive data was analyzed for THD, VJ, Quad<sub>60</sub>, Quad<sub>180</sub>, Ham<sub>60</sub>, and Ham<sub>180</sub> to attain means, maximums, standard deviations, and confidence intervals for the dominant and non-dominant limbs. Simple linear regressions were utilized to determine variance predictions and create prediction equations, while Bivariate Pearson correlations were used to determine the strength of the predictive relationship. The predictive relationship was considered strong if the correlation was > 0.5 and moderate to weak if the correlation was < 0.5 based on previous literature regarding these hop tests. All significance levels were set *a priori* at  $P \leq 0.05$ . A Kolmogorov-Smirnoff test was ran, and none of the statistical analysis violated assumptions of normality.

## RESULTS

Dominant and non-dominant limb descriptive statistics for THD, VJ, Quad<sub>60</sub>, Quad<sub>180</sub>, Ham<sub>60</sub>, and Ham<sub>180</sub> scores can be seen in Table 1.

**Table 1:** Descriptive Statistics for Triple Hop for Distance, Vertical Jump, and Isokinetic Testing in Firefighter Personal Protective Equipment.

	Dominant Limb Mean $\pm$ SD	Dominant Limb Confidence Intervals	Non-Dominant Limb Mean $\pm$ SD	Non-Dominant Limb Confidence Intervals
Triple Hop for Distance (cm)	358.83 $\pm$ 90.54	325.62, 392.04	355.83 $\pm$ 89.64	322.95, 388.72
Vertical Jump (cm)	44.90 $\pm$ 9.97	41.11, 48.7	44.90 $\pm$ 9.97	41.11, 48.7
Quadriceps Peak Torque (Nm)				
60°/s	198.44 $\pm$ 63.58	175.12, 221.76	189.26 $\pm$ 50.39	125.9, 369.40
180°/s	149.50 $\pm$ 43.24	133.63, 165.36	145.54 $\pm$ 40.08	130.84, 160.24
Hamstrings Peak Torque (Nm)				
60°/s	129.36 $\pm$ 28.40	118.94, 139.78	129.17 $\pm$ 28.12	118.86, 139.49
180°/s	110.67 $\pm$ 27.45	100.61, 120.74	108.30 $\pm$ 26.42	98.61, 117.99

Notes: cm: centimeters; Nm: Newton meters; °/s: degrees per second; SD: standard deviation.

On the dominant limb the THD was able to predict 66.5% of the variance in VJ scores yielding a prediction equation of  $Y_{VJ} = 11.46 + 0.93X_{THD-DOM}$ . On the non-dominant limb the THD was able to predict 63.2% of the variance yielding a prediction equation of  $Y_{VJ} = 12.25 + 0.09X_{THD-NONDOM}$ . In relation to concentric strength of Quad<sub>60</sub> and Quad<sub>180</sub> the THD was able to predict 25.1% and

29.4% of the variance on the dominant limb and 42.7% and 34.5% of the variance on the non-dominant limb respectively. The variance predictions for Quad<sub>60</sub>, and Quad<sub>180</sub> yielded the following predictive equations:

$$Y_{Q60} = 72.32 + 0.35X_{THD-DOM}$$

$$Y_{Q180} = 56.61 + 0.26X_{THD-DOM}$$

$$Y_{Q60} = 57.40 + 0.37X_{THD-NONDOM}$$

$$Y_{Q180} = 52.11 + 0.26X_{THD-NONDOM}$$

In relation to the concentric strength of Ham<sub>60</sub>, and Ham<sub>180</sub> the THD was able to predict 25.6% of and 29.2% of the variance on the dominant limb and 46.1% and 30.7% of the variance on the non-dominant limb respectively. The variance predictions for Ham<sub>60</sub>, and Ham<sub>180</sub> yielded the following predictive equations:

$$Y_{H60} = 72.40 + 0.16X_{THD-DOM}$$

$$Y_{H180} = 51.90 + 0.16X_{THD-DOM}$$

$$Y_{H60} = 53.40 + 0.21X_{THD-NONDOM}$$

$$Y_{H180} = 51.90 + 0.16X_{THD-NONDOM}$$

Statistical analysis identified significant findings in all dependent variables of interest on both the dominant and non-dominant limb. Predictable level of variance (*R*<sup>2</sup>) and standard error of estimation between THD and VJ and isokinetic testing are outlined Table 2.

**Table 2:** Variance Comparisons of Lower Extremity Strength and Power to Triple Hop for Distance.

Variable	Dominant Limb <i>R</i> <sup>2</sup>	Dominant Limb <i>p</i>	Dominant Limb Standard of Error Estimation	Non-Dominant Limb <i>R</i> <sup>2</sup>	Non-Dominant Limb <i>p</i>	Non-Dominant Limb Standard of Error Estimation
Vertical Jump	0.665	<0.01	6.09	0.632	<0.01	6.38
Quadriceps Peak Torque						
60°/s	0.251	<0.01	55.99	0.427	<0.01	336.28
180°/s	0.294	<0.01	36.97	0.345	<0.01	32.99
Hamstring Peak Torque						
60°/s	0.256	<0.01	24.91	0.461	<0.01	21.00
180°/s	0.292	<0.01	23.49	0.307	<0.01	22.36

Notes: °/s: degrees per second.

Bivariate Pearson correlations comparing THD scores with VJ, Quad<sub>60</sub>, Quad<sub>180</sub>, Ham<sub>60</sub>, and Ham<sub>180</sub> reveal strong predictive values in the dominant limb (Table 3) and non-dominant limb (Table 4) respectively.

**Table 3:** Dominant Limb Bivariate Pearson Correlations for Triple Hop for Distance, Vertical Jump, and Quadriceps and Hamstring Peak Torque in Firefighter Personal Protective Equipment.

	Triple Hop for Distance	Vertical Jump	Quadriceps Peak Torque		Hamstrings Peak Torque	
			60°/s	180°/s	60°/s	180°/s
Triple Hop for Distance	1.000	0.816 <sup>a</sup>	0.501 <sup>a</sup>	0.542 <sup>a</sup>	0.506 <sup>a</sup>	0.540 <sup>a</sup>
Vertical Jump		1.000	0.784 <sup>a</sup>	0.828 <sup>a</sup>	0.540 <sup>a</sup>	0.751 <sup>a</sup>
Quadriceps Peak Torque			1.000	0.933 <sup>a</sup>	0.825 <sup>a</sup>	0.817 <sup>a</sup>
60°/s				1.000	0.854 <sup>a</sup>	0.901 <sup>a</sup>
180°/s						
Hamstrings Peak Torque					1.000	0.902 <sup>a</sup>
60°/s						1.000
180°/s						

Notes: °/s: degrees per second; <sup>a</sup> Indicates  $p < .01$

**Table 4:** Non-Dominant Limb Bivariate Pearson Correlations for Triple Hop for Distance, Vertical Jump, and Quadriceps and Hamstring Peak Torque in Firefighter Personal Protective Equipment.

	Triple Hop for Distance	Vertical Jump	Quadriceps Peak Torque		Hamstrings Peak Torque	
			60°/s	180°/s	60°/s	180°/s
Triple Hop for Distance	1.000	0.795 <sup>a</sup>	0.653 <sup>a</sup>	0.587 <sup>a</sup>	0.679 <sup>a</sup>	0.555 <sup>a</sup>
Vertical Jump		1.000	0.825 <sup>a</sup>	0.850 <sup>a</sup>	0.846 <sup>a</sup>	0.753 <sup>a</sup>
Quadriceps Peak Torque			1.000	0.960 <sup>a</sup>	0.912 <sup>a</sup>	0.866 <sup>a</sup>
60°/s				1.000	0.930 <sup>a</sup>	0.920 <sup>a</sup>
180°/s						
Hamstrings Peak Torque					1.000	0.949 <sup>a</sup>
60°/s						1.000
180°/s						

Notes: °/s: degrees per second; <sup>a</sup> Indicates  $p < .01$

## DISCUSSION

This study explored the addition of PPE in non-firefighter trained individuals. The methodology was chosen to replicate the effect of a new load carriage on basic fire recruits entering the workforce. Our findings support the THD as a physical performance measure to assess LE strength and power in both the dominant and non-dominant limb in untrained individuals wearing firefighter PPE.

Lower Extremity Power: VJ is regarded as a validated measure to assess lower extremity power as part of a comprehensive program for readiness to participate in activity or perform job specific tasks (9, 11). Previous authors have established the connection between LE power and mobility in both older adults with fall risk (2), and in highly athletic individual's ability to execute sport specific tasks (6). The correlation between the THD and VJ test in healthy individuals without any personal protective equipment has been supported by previous authors

(9, 11). Furthermore, previous authors have established that the force production across the ankle, knee, and hip joints still require the same maximal generation of power required in the THD as the VJ (9, 11). The findings of our study support the THD as a predictor of power in untrained individuals wearing firefighter PPE, making the THD a tool that can be used to assess musculoskeletal power in the firefighter population.

To achieve maximal height for the VJ, synergistic movements between the agonist and antagonist muscle groupings on both limbs in the LE must occur to propel the body upward (19). The increase in mass while wearing firefighter PPE decreases the ability to achieve maximal VJ height (1). Despite the decrease in performance due to mass of the PPE, the THD on both the dominant and non-dominant limb is still a strong predictor of VJ scores. This relationship validates the use of the THD in firefighter population to assess musculoskeletal power despite reductions in performance caused by the increased mass of PPE. While both the VJ and THD physical performance tests require little time and resources to complete, use of the THD allows sports medicine practitioners to discern between deficiencies and asymmetries that may not be present bilaterally and can be completed without the need for a vertical jump measurement tool.

**Lower Extremity Strength:** Isokinetic testing is regarded as the gold standard measure for assessing LE strength in both healthy and injured populations (8, 18). The strong predictive relationship between the THD and measures of LE strength at both 60°/s and 180°/s for the hamstrings and quadriceps in a healthy population have been established by previous authors (11). Isokinetic testing procedures in our study were done with the participant in a gravity-eliminated position seated on the dynamometer. The movements required testing the hamstrings and quadriceps at both 60°/s and 180°/s on the dynamometer were also open kinetic chain. Based on isokinetic testing procedures, the impact of the added mass of firefighter PPE on measures of LE strength was likely minimal. Inversely, the impact of the added mass of PPE on THD scores was prominent when compared to normative data in a healthy population from previous studies (1, 3).

While isokinetic testing is valid and reliable for assessing LE strength, it can be inferred the open kinetic nature of the testing position in addition to the gravity-eliminated position cannot capture the full impact the mass of PPE has on the body. Despite this difference, the THD was still found to be a strong predictor of LE strength on both the dominant and non-dominant limb in the quadriceps and hamstrings at both angular velocities in our study. This suggests that the THD is more representative of a workplace scenario in firefighters wearing PPE when assessing measures of LE strength. Given that isokinetic testing equipment is expensive and inaccessible to most fire departments, the THD provides a valid and cost effective alternative to measure LE strength in PPE.

**Practical Application:** As previously mentioned, strength and power are integral for firefighters to complete job specific tasks in an effective and efficient manner. A firefighter's inability to complete job specific tasks effectively and efficiently due to strength and power deficits creates a high potential for injury given inherent dangers in the fire ground. Given the high number of time-loss injuries sustained by structural firefighters in the fire ground, coupled with annual

NFPA data showing no indication of injury rates slowing down, there is an exceedingly urgent need to research and implement interventions throughout the lifecycle of a firefighter's career (12).

**Limitations and Future Research:** As an exploratory venture to determine the utility of the THD while an individual is wearing PPE, this study has a few limitations worth noting. In our study we intentionally chose to utilize participants without firefighter experience or training in order to more closely emulate firefighter recruits unfamiliar with the load carriage of PPE. Additionally, the age of the participants was young compared to the average age of current firefighters; however it was representative of the average age of firefighter recruits entering the academy or workforce. Future work should examine if these relationships hold true in career and volunteer firefighters and examine if chronological age has an impact on the relationship among THD length, lower extremity strength, and lower extremity power. Future research should additionally evaluate the feasibility of integrating the THD during the work performance evaluation for firefighters, and how the effect of the ratio of PPE mass to body mass changes THD performance.

**Conclusion:** Our study supports the THD as a unilateral physical performance measure to predict lower extremity strength and power while wearing firefighter PPE. The THD, either as a standalone physical performance measure or part of a more comprehensive screening program, is a tool that clinicians and practitioners can utilize as part of a work performance evaluation to identify the need for corrective interventions for LE injury prevention and promotion of high caliber job performance.

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