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The predictive value of general movement tasks in assessing occupational task performance

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Abstract.
BACKGROUND: Within the context of evaluating individuals' movement behavior it is generally assumed that the tasks chosen will predict their competency to perform activities relevant to their occupation.
OBJECTIVE: This study sought to examine whether a battery of general tasks could be used to predict the movement patterns employed by firefighters to perform select job-specific skills.
METHODS: Fifty-two firefighters performed a battery of general and occupation-specific tasks that simulated the demands of firefighting. Participants' peak lumbar spine and frontal plane knee motion were compared across tasks.
RESULTS: During 85% of all comparisons, the magnitude of spine and knee motion was greater during the general movement tasks than observed during the firefighting skills. Certain features of a worker's movement behavior may be exhibited across a range of tasks. Therefore, provided that a movement screen's tasks expose the motions of relevance for the population being tested, general evaluations could offer valuable insight into workers' movement competency or facilitate an opportunity to establish an evidence-informed intervention.

Keywords: Firefighter, injury, movement screen

1. Introduction

Links between individuals' motion patterns and their risk of injury have motivated researchers and practitioners to appraise general movements patterns [1, 2]. However, an assumption of this approach is that motion patterns exhibited during the performance of such movements are reflective of those employed during work, sport and leisure activities. If this is not the case, attempts to generalize may lead to inaccurate characterizations (e.g. high risk) and inappropriate exercise or ergonomic interventions. For instance, efforts are often made to establish an overall risk via visual observation of general whole-body movements (e.g. squat, lunge) that may not reflect the motion patterns associated with athletic or occupational injuries [3–5]. Musculoskeletal injuries account for approximately half of all fireground injuries sustained by firefighters [6], but to date there is no evidence to suggest that the movement strategies used to execute any of the complex job-specific skills could be predicted via observation of general movements.

It may be desirable to characterize individuals' movement behavior within the context of their occupational demands, or more specifically, in relation to relevant activities that impose risk. Firefighters would be

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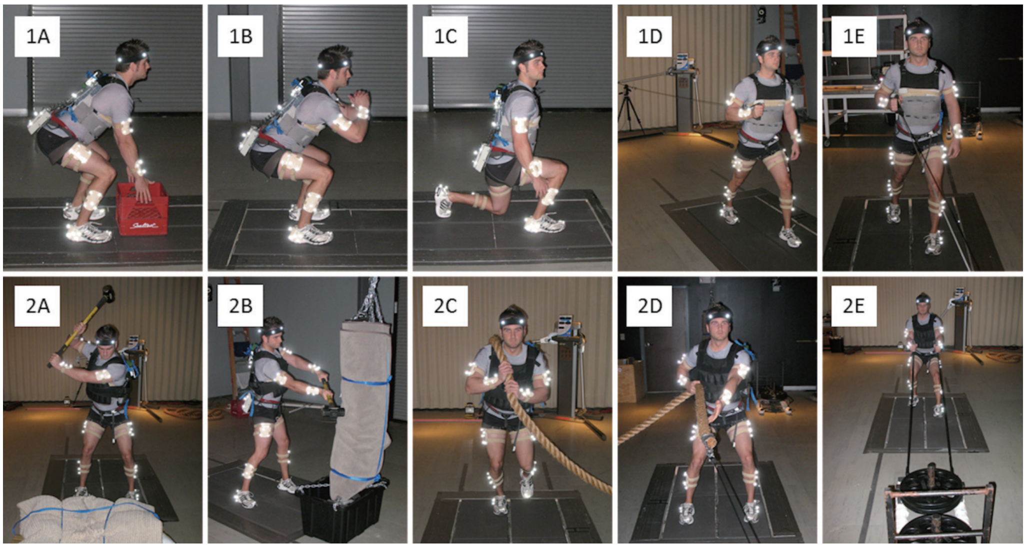

Fig. 1. The general (1A – Lift; 1B – Squat; 1C – Lunge; 1D – Push; and 1E – Pull) and job-specific tasks (2A – Chop; 2B – Forced entry; 2C – Hose drag; 2D – Hose pull; and 2E – Heavy drag). (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/WOR-141902)

observed while performing job-specific skills such as pulling hose, forcing entry or extricating victims from a building, and their motion patterns would be quantified and used in combination with knowledge of hypothesized or demonstrated injury mechanisms to estimate risk. But such an approach is not always possible or practical, and thus generalizing to some degree is necessary, particularly for populations performing non-stereotypical work. In the event that a specific task is identified as high-risk within a particular demographic and there are hypothesized injury mechanisms with which to compare key motion characteristics (i.e. spine flexion), the specific task should arguably be included in all future evaluations for that population. For example, within the sport literature, the occurrence of anterior cruciate ligament (ACL) injury has been predicted, in part, by evaluating individuals' movement patterns during the performance of injury-causing activities [1]. However, many researchers and practitioners continue to use general, non-specific tasks to categorize and describe the capacity of "occupational athletes" such as firefighters [7], soldiers [8], and police officers [9], without giving adequate consideration to their specific demands. There may be merit in using such an approach beyond convenience, although without a scientific basis the application of any findings is limited. Therefore, the objective of this study was to investigate the degree to which performance of a battery of general tasks could be used to predict the motion patterns exhibited by firefighters when performing job-specific skills.

2. Methods

2.1. Participant selection

Fifty-two firefighters from the Pensacola Fire Department participated in this investigation. All men were free of musculoskeletal injury at the time of testing and were on full active duty. Their mean (SD) age, height and body mass were 37.7 (9.7) years, 1.81 (0.06) m and 92.1 (14.4) kg, respectively. The University's Office of Research Ethics, the Baptist Hospital Institutional Review Board and the City of Pensacola approved the investigation and participants gave their informed consent before the data collection began.

2.2. Task selection

The general tasks, shown in Fig. 1, were chosen for two reasons: 1) to reflect five whole-body movement patterns commonly performed by firefighters throughout the course of a shift, and 2) to challenge the control of joint motions, or injury mechanisms, that may contribute to the musculoskeletal injuries most commonly sustained by firefighters (i.e. low back and knees) [10]. The five tasks were: 1) Lift – individuals lifted a box ($0.33 \times 0.33 \times 0.28$ m) from the floor to waist height; 2) Squat – individuals performed a bodyweight squat (depth was self-selected); 3) Lunge – individuals lunged forwards onto their right leg and returned to the starting position; 4) Push – from a staggered stance (left leg forwards), individuals performed a cable press with the right arm; 5) Pull – from a staggered stance (left leg forwards), individuals performed a cable pull with the right arm.

In consultation with a group of firefighters, each occupation-specific task (Fig. 1) was designed to simulate a firefighting skill performed during one of two standardized events: 1) the Candidate Physical Ability Test (CPAT), which was developed by the International Association of Fire Fighters (IAFF) and Fire Chiefs (IAFC) to test candidates' ability to perform tasks consistent with the duties of a firefighter, or 2) the Firefighter Combat Challenge, a 5-task event comprising simulated fireground tasks commonly performed by incumbents for training purposes. The five occupation-specific tasks were: 1) Chop – individuals struck an object on the ground with a 4.5 kg sledgehammer (direction of swing was self-selected); 2) Forced entry – individuals struck a ceiling-mounted object with a 4.5 kg sledgehammer (direction of swing was self-selected); 3) Hose drag – a 6.4 cm diameter rope, connected to a cable machine (Keiser®, Fresno, CA, U.S.A.) was placed over the right shoulder and participants initiated forward movement from a staggered stance (left foot forwards); 4) Hose pull – a 6.4 cm diameter rope was pulled approximately 5 m in a hand-over-hand fashion with resistance provided via a cable (Keiser®, Fresno, CA, USA) attached to the end of the rope; 5) Heavy drag – an 81.8 kg sled was pulled approximately 5 m.

2.3. Procedures

Participants were instrumented with reflective markers and familiarized with the tasks using a standard set of instructions. Because load and speed impact individuals' movement behavior [11] each general task was performed with four load and speed combinations. The initial exposure to each task comprised a low external load and movement speed (LLLV – low load, low velocity). Lifting was performed with 6.8 kg, squats and lunges were completed with bodyweight, and the push and pull loads were set at 4kg and 6.5 kg, respectively. The tasks were randomized (three repetitions each) and approximately 15 s and 60 s rest was given between each repetition and task, respectively. Once all tasks had been completed the movement speed and external load were modified in three ways: 1) low load, high velocity (LLHV) – increase in speed; participants completed each trial as fast as was comfortable; 2) high load, low velocity (HLLV) – increase in load; lifts were performed with 22.7 kg, squats and lunges were completed with a weighted vest (18.2 kg), and the push and pull loads were increased to 9.8 kg and 13.6 kg, respectively; 3) high load, high velocity (HLHV) – increase in speed and load. Each condition was performed sequentially based on the expected musculoskeletal demands such that systematic comparisons could be made across participants. Because increasing the squat and lunge load required that a weight vest be worn, it was hypothesized that randomizing the level of exposure could increase the possibility of measurement error.

Following the HLHV condition, participants performed three trials of each firefighting task in random order. Approximately 15 s and 60 s rest was given between trials and tasks, respectively. To better simulate the occupational demands of the chop and forced entry, five repetitions were performed within each trial, of which the middle three were analyzed. Consistent with the protocol devised for the CPAT by the IAFF and IAFC, an 18.2 kg vest was worn throughout this phase of testing to simulate the mass of firefighters' personal protective equipment. The two hose handling tasks were resisted with 9.8 kg to reflect the external demands of the hose handling tasks performed during the CPAT. Three-trial means for each task were analyzed. No feedback was given regarding task performance.

2.4. Data collection and signal processing

Three-dimensional motion data were measured using a passive motion capture system (Vicon, Centennial, CO, USA). Reflective markers were placed on 23 anatomical landmarks to assist in defining the endpoints of the trunk, pelvis, thighs, shanks and feet. Participants' hip joint centers (HJC) and knee joint axes (KJA) were determined "functionally" using similar methods to those described by Begon et al. [12] and Schwartz and Rozumalski [13]. Sets of 4 or 5 markers, fixed to rigid pieces of plastic, were secured to the trunk, pelvis, thighs, shanks and feet with Velcro® straps and used to track the position and orientation of each body segment in 3D space. The marker data was collected at 160 Hz and smoothed with a low-pass filter (6 Hz).

2.5. Data analyses

Participants' motion patterns were characterized with five variables, each chosen to reflect a possible mechanism for low back [14,15] or knee [1,16,17] injury. The five variables were: 1–3) lumbar spine flexion/extension (FLX), lateral bend (BND) and axial twist (TST) – the relative orientation of the trunk was expressed with respect to the pelvis and relaxed upright standing trial was defined as zero degrees; and 4–5) left (LFT) and right knee (RGT) position relative to the frontal plane – each knee joint's position (medial/lateral) was described relative to a body-fixed plane created using the corresponding hip, ankle and distal foot.

To objectively define the start and end of each trial, event detection algorithms were created in Visual 3D^{TM}. The chop and forced entry task data were processed to reflect a right-handed swing (i.e. data were inverted for left handed individuals). Maximums and minimums of the five variables were computed for each repetition and the "peak" of each variable was described as the deviation (maximum or minimum) hypothesized to be most relevant to the types of injuries sustained by firefighters (i.e. FLX – flexion, BND and TST – maximum deviation in either direction, and LFT and RGT – medial displacement).

2.6. *Statistical analyses*

To facilitate task comparisons, each of the five dependent measures (maximum and minimum) was normalized to the range observed across the general patterns. Briefly, the maximums and minimums for the lift, squat, lunge, push and pull were used to compute a general task range (highest max – lowest min) and midpoint (e.g. 50° spine flexion, $-20°$ spine extension, midpoint of 15° flexion). This midpoint was then subtracted from the maximums and minimums of each task (e.g. normalized range of 35° to $-35°$) and the result was expressed with respect to half the computed range (e.g. range of 70°, therefore normalized range of 1 to -1). As such, the maximums and minimums of the general tasks were bounded by scores of -1 and 1. Normalized scores outside of this range implied that individuals' general task performance was unable to capture the magnitude of deviation observed during the firefighting skill. Given that participants performed the lunge, push and pull with the right side only, symmetry was assumed when describing the maximums and minimums for each of these general tasks. Normalized comparisons were made on the group's data and that of each participant and the number of instances whereby the generalized range was exceeded was computed.

3. Results

In 163 of 200 comparisons (5 occupation-specific tasks $\times$ 10 minimums and maximums $\times$ 4 load/speed conditions), the magnitude of spine and frontal plane knee motion used during the general tasks exceeded that employed while performing the firefighting skills (Fig. 2). The FLX adopted to perform each occupation-specific task fell within the normalized range (i.e. -1 and 1), irrespective of the load and movement speed used for comparisons. Interestingly, similar findings were noted for TST despite the rotational nature of the chop and forced entry. The magnitude of LFT and RGT was also greater during the general tasks for every comparison with the exception of two cases for each variable; minimum chop and heavy drag for LFT (↑ medial deviation), and minimum hose drag (↑ lateral deviation) and maximum heavy drag for RGT. Not surprisingly, the magnitude of BND observed during the general tasks greater than that employed during the firefighting skills in only 6 of 10 instances for LLLV; however, increasing the load and speed did widen the normalized boundaries. During the HLHV condition only the minimum hose drag and maximum forced entry were of a magnitude that was less than the generalized range.

Similar findings were observed when each firefighter's data was investigated separately (Fig. 3); however, the group's response did not reflect the responses of every individual. With the exception of the heavy drag TST noted during the HLHV condition, at least one participant was found to exhibit a maximum or minimum FLX, BND, TST, LFT and RGT while performing the firefighting tasks that exceeded the general limits. Expressed as a percentage of the total number of participant scores (maximums and minimums) across all firefighting tasks, FLX was found to fall outside the normalized boundaries with the lowest frequency (5.6% across all load/movement speed conditions), followed by TST (12.8%), RGT (23.3%), LFT (26.0%) and BND (26.0%). Furthermore, the general tasks' load and movement speed did influence the frequency with which the maximum and minimum deviation was bounded by the generalized range; across all tasks and variables only 14.6% of the participants' scores fell outside during the HLHV condition, in comparison to 17.5%, 20.3% and 22.7% for the LLHV, HLLV, and LLLV conditions, respectively.

4. Discussion

The findings suggest that there may be attributes, or "key features", of an individual's movement behavior observed during a general screen that can be generalized across a range of occupation-specific activities.

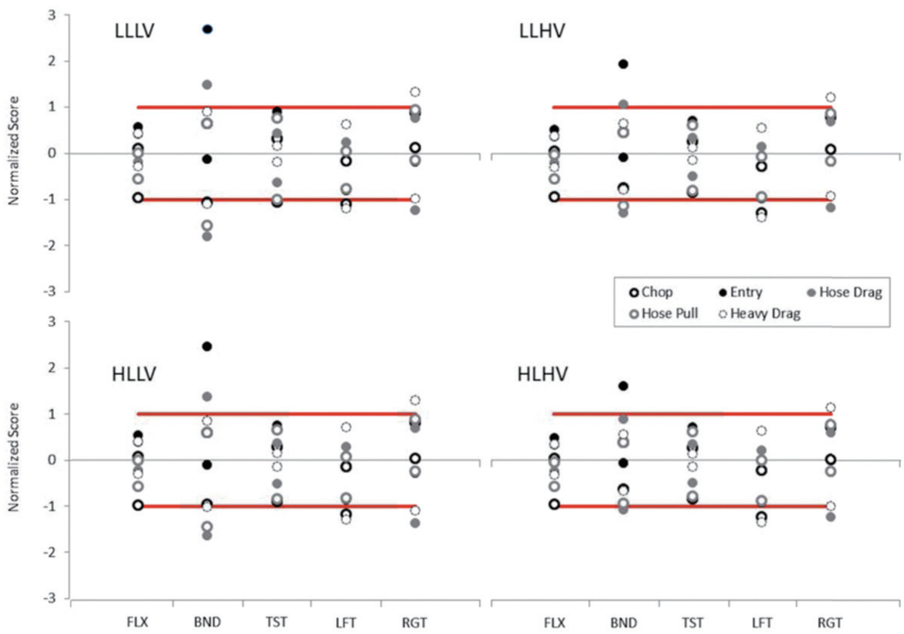

Fig. 2. Normalized maximums *and* minimums for each firefighting task (i.e.each task is described by two data points). Symmetry was assumed for the lunge, push and pull. The solid lines at −1 and 1 represent the maximums and minimums observed for the general tasks. Scores outside of this range imply that the group's general task performance was unable to capture the magnitude of deviation observed during the firefighting skill in question. Each of the load/movement speed conditions are presented; LLLV – low load, low velocity; LLHV – low load, high velocity; HLLV – high load, low velocity; HLHV – high load, high velocity. (FLX – spine flexion/extension; BND – spine lateral bend; TST – spine twist; LFT – left knee position; and RGT – right knee position). (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/WOR-141902)

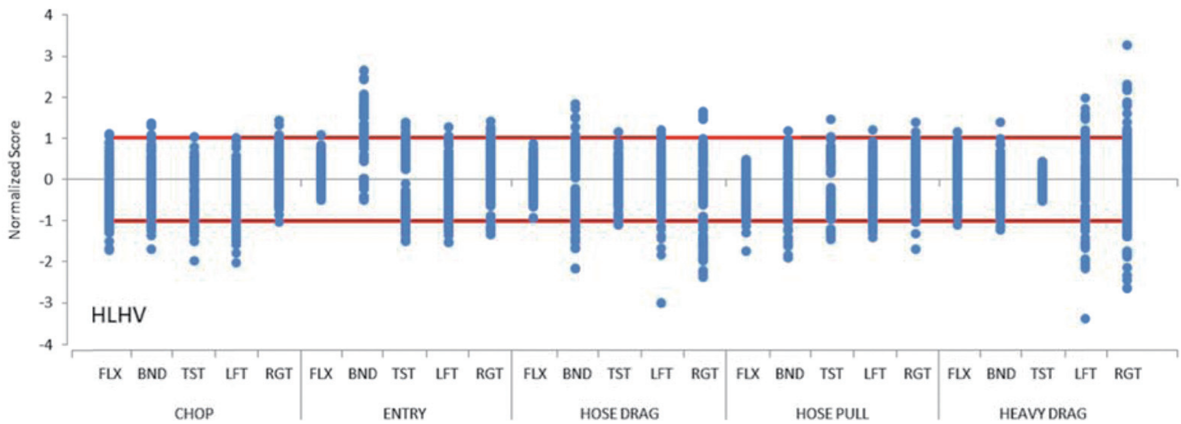

Fig. 3. Normalized maximums and minimums for each participant (circles). Symmetry was assumed for the lunge, push and pull. The solid lines at −1 and 1 represent the subject-specific maximums and minimums observed for the general tasks. Scores outside of this range imply that the individual's general task performance was unable to capture the magnitude of deviation observed during the firefighting skill in question. Data for the high load, high velocity (HLHV) condition is presented. (FLX – spine flexion/extension; BND – spine lateral bend; TST – spine twist; LFT – left knee position; and RGT – right knee position). (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/WOR-141902)

Given links between individuals' motion patterns and their risk of injury [1,7], and the incidence of lower back and knee injuries sustained by firefighters [10,18], there may be merit in evaluating incumbents' control of spine and frontal plane knee motion for the purpose of establishing risk. Obviously it would be difficult to simulate the demands of every firefighting skill with general patterns such as lifting, lunging or pushing, but the results of this study suggest that it may be unnecessary. Simply knowing if and how much spine flexion might be exhibited, for example, may be sufficient to devise an appropriate strategy to modify an individual's movement behavior, via changes to their fitness or awareness, such that it would be perceived as a positive adaptation. Both the group and subject-specific analyses in this study showed that with the exception of BND during the forced entry, the magnitude of spine and frontal plane knee motion observed for the battery of general patterns exceeded that exhibited by participants while they performed the simulated firefighting tasks. In other words, select features of the lift, squat, lunge, push and pull patterns could be used to describe the kinematics of occupation-specific activities. Individual differences were seen, but surprisingly, few participants demonstrated greater spine and frontal plane motion while performing the more complex tasks designed to simulate the elevated demands of firefighting.

Over the past ten years, tremendous progress has been made towards identifying those at risk of non-contact anterior cruciate ligament (ACL) injuries, in part because researchers have contrasted the movement patterns exhibited during non-contact ACL injury events to ACL loading mechanisms [1]. This approach has afforded an opportunity to devise science-based interventions that alter individuals' movement behavior and attenuate joint loading [19,20]. In light of their successes, scientists and practitioners have begun exploring the utility of general whole-body movement evaluations to establish the risk of *any* non-contact musculoskeletal injury with occupational groups such as firefighters [21], soldiers [8], and police officers [9], who engage in physically demanding activities that cannot be easily modified based on ergonomic principles. Critical observations are commonly described so that individuals' motion patterns can be objectively categorized as "good" or "bad", although quite often there is little evidence linking the criteria being used for these purposes to the types of injuries most commonly sustained by the population being tested. For example, many of the injuries sustained by fire service personnel are described as sprains and strains affecting the lower back [10], yet some of the whole-body screening tools being used to predict injury amongst this population (e.g. Functional Movement Screen^{TM} (FMS)) do not use lumbar spine motion as a criterion with which to evaluate incumbents' movement competency [7]. It may be for this reason that the FMS has shown conflicting success as an injury prediction tool [4,8,22]. Secondly, and perhaps a more intriguing aspect of the "general screen", is that unique criteria are sometimes used to describe each screening task in an effort to aid the observer [3,23,24]. When every pattern being tested is categorized with different observations (a characteristic of task specificity), it becomes exceedingly difficult to generalize the screen's findings to a different set of tasks that would be more relevant to the individual's occupational demands.

Evaluating the ability to run is probably best accomplished through an analysis of running. There are physiological, mechanical and behavioral adaptations specific to the act of running (or whichever activity is being performed) that may not be captured with an alternative activity (e.g. cycling). However, because all endurance events impose similar general demands on the cardiovascular system [25], there are also specific attributes or key features of an individual's ability (e.g. VO_2 max) that can be evaluated with a variety of tests. Conceivably, the evaluation of movement could be viewed in the same way. Assessing an firefighter's capacity to perform a particular skill (e.g. forced entry) would require that said skill be evaluated, but perhaps their general movement behavior, including the risk of sustaining a non-contact musculoskeletal injury, could be assessed using a battery of general tasks that impose similar movement demands on the body (e.g. control of spine flexion). Individuals could then be categorized based on the magnitude of "uncontrolled" motion exhibited and their general tendency to adapt their movement patterns in response to an elevated exposure comprising load, repetition, or duration. For firefighters, there may be merit in examining the movement behaviors employed in response to occupational exposures such as wearing an SCBA, heat or fatigue; however, if the aim is simply to better understand a worker's tendency to exhibit a particular risk factor such as spine or frontal plane knee motion, elevating the demands of a general screen could accomplish the same objective. In this study, participants exhibited more spine and frontal plane knee motion while performing the general tasks when the load and speed was increased. This finding highlights the fact that if administering a general screen, tasks of higher demand will provide a more conservative estimate of the deviation that might be observed while performing a job-specific activity comprising similar movement demands, perhaps irrespective of the exposure. The finding further suggests that limiting a movement-based evaluation to low-demand activities could skew the interpretation of any results and lead to the development of an inappropriate intervention, particularly given that a worker's abilities and perception of risk will impact their movement behavior. Injuries are only influenced in part by the way an individual moves, but in many occupations it is one of the only factors that can be modified to attenuate the applied tissue load, maintain loading tolerance, and thus reduce injury risk [26].

The general tasks (i.e. lift, squat, lunge, push and pull) included in this investigation were administered in such a way that they would impose a range of movement demands, thus eliciting a variety of responses amongst participants. For example, the mechanics of lifting and squatting were expected to expose spine flexion/extension and frontal plane knee motion patterns that would not be observed while pushing and pulling. On the other hand, the pushes and pulls were performed unilaterally and with a staggered stance so that the firefighters' control of spine lateral bend and twist could be observed. Had a bilateral pattern been used, participants' capacity to resist these joint motions would not have been challenged, making it difficult to approximate the deviation that was adopted while performing the battery of more demanding, job-specific tasks. It is important to note that there was not one general pattern that was better able to predict participants' ability to control each of the joint motions investigated, or one that was more closely related to a particular key feature of the firefighting skills. Together however, the five general tasks were able to approximate the maximum deviation observed while participants performed the simulated patterns. Therefore, if using a general screen to establish the risk of musculoskeletal injury, or assist in devising an appropriate intervention for any occupation, it is recommended that the screening tasks chosen be characterized by key features and of a variety such that their demands are able to expose the motion patterns of interest.

5. Conclusions

Movement behavior is influenced by a number of personal, task and environmental factors; however, when the execution of a task is characterized by select key features instead of a gross movement strategy, two different patterns can describe similar aspects of a worker's movement behavior. In this study, the maximum spine and frontal plane knee motion exhibited by firefighters while performing five occupation-specific skills was lower than that displayed during the performance of five general whole-body tasks comprising similar movement demands (e.g. control of spine flexion). Therefore, there may be merit in using general tasks to estimate one's movement competency or to facilitate an appropriate intervention strategy, provided that the tasks are chosen and administered in such a way that they challenge participants' capacity to control the motions of interest.

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