The Influence of Load and Speed on Individuals' Movement Behavior

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Abstract

Frost, DM, Beach, TAC, Callaghan, JP, and McGill, SM. The influence of load and speed on individuals' movement behavior. *J Strength Cond Res* 29(9): 2417–2425, 2015—Because individuals' movement patterns have been linked to their risk of future injury, movement evaluations have become a topic of interest. However, if individuals adapt their movement behavior in response to the demands of a task, the utility of evaluations comprising only low-demand activities could have limited application with regard to the prediction of future injury. This investigation examined the impact of load and speed on individuals' movement behavior. Fifty-two firefighters performed 5 low-demand (i.e., light load, low movement speed) whole-body tasks (i.e., lift, squat, lunge, push, and pull). Each task was then modified by increasing the speed, external load, or speed and load. Select measures of motion were used to characterize the performance of each task, and comparisons were made between conditions. The participants adapted their movement behavior in response to the external demands of a task (64 and 70% of all the variables were influenced [$p \leq 0.05$] by changing the load and speed, respectively), but in a manner unique to the task and type of demand. The participants exhibited greater spine and frontal plane knee motion in response to an increase in speed when compared with increasing loads. However, there were a large number of movement strategies exhibited by individual firefighters that differed from the group's response. The data obtained here imply that individuals may not be physically prepared to perform safely or effectively when a task's demands are elevated simply because they exhibit the ability to perform a low-demand activity with competence. Therefore, movement screens comprising only low-demand activities may not adequately reflect an individual's capacity, or their risk of injury, and could adversely affect any recommendations that are made for training or job performance.

Key Words firefighter, injury, low back, knee, movement screen, prevention

Introduction

Evaluating an individual's capacity (i.e., ability, awareness, and understanding) to enhance performance or prevent the occurrence of injury likely requires situational context. It is this notion that forms the basis for this study; can a movement evaluation comprising low-demand tasks be used to predict individuals' movement competency when the demands are elevated? If it cannot, using an unloaded lifting task to assess an individual's risk of sustaining a lifting-related occupational injury may not be appropriate. Injuries are sustained when individuals' demands exceed their capacity, and quite often it is the demands and not the task (e.g., lifting) itself that elicit the adapted movement behaviors that cause problems (24,35). Poorly chosen or executed movement patterns create tissue stresses that lead to both acute and chronic injury (4,17).

Dufek et al. (10) proposed that the way an individual responds to varying demands ranges along a continuum from total accommodation to complete dismissal. The group theorized that the strategy chosen to perform a given task would depend on the recognition of its demands and the perceived severity of its potential effects on the body. Although the primary basis for such an assertion was previous work documenting individual variation in impact forces while running (1) and landing from a jump (5,9), a similar framework may be applicable to the study of movement patterns. When presented with 2 tasks of the same pattern (e.g., lifting), but different demands (e.g., heavy vs. light load), some individuals may perform both with a very similar movement strategy; others, however, may adapt their movement behavior and exhibit varying degrees of task demand dependence. For example, Flanagan and Salem (11) found that among participants, a range of movement strategies were used to perform a squat, but interestingly, convergence in the net joint movements was noted as the load increased from 25 to 100% of the 3-repetition maximum.

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29(9)/2417–2425

Journal of Strength and Conditioning Research

The degree to which a movement strategy is altered in response to an increased or decreased task demand may depend in part on the perception of risk as was suggested by Dufek et al. (10); however, additional factors such as awareness, coordination, and fitness (e.g., strength, endurance, and cardiorespiratory efficiency) may be equally important. Speculating as to the exact reason why a pattern is changed would therefore be very difficult, particularly given the lack of evidence to support a homogeneous response across a group of participants. Faced with the task of picking up a pencil off the floor, highly astute, physically capable firefighters may not choose to adopt the same strategy as they would to lift a heavy piece of equipment, if the perception of the pencil task was such that it could not cause harm. However, highly astute firefighters with poor fitness may exhibit similar patterns for both tasks, because they lack the strength necessary to perform the heavy lift in such a manner that would be perceived as "safe" or "good"; the demands of the task exceed their capacity to perform in a safe and effective manner.

Without a framework to describe a pattern as good or bad, the way in which an individual responds to varying demands could arguably be viewed as secondary to simply acknowledging the fact that their movement patterns might be context specific. Whole-body movement screens, wherein individuals are asked to perform a battery of tasks, are frequently used to assess one's ability to perform various general patterns (16,20,22,29) (e.g., squat and lunge), yet little consideration is ever given to the possibility that a task's demands may influence the way an individual moves. Many of these screens comprise bodyweight patterns, and individuals are instructed to perform in a slow, controlled manner, irrespective of the population being tested or the long-term rationale behind the evaluation. For example, the functional movement screen, a 7-task test created to evaluate joint mobility and stability (7,8), has been used as a means to predict injuries in athletes (18,22,33) and firefighters (3,29) and to guide recommendations for training (16,21), despite the fact that its tasks' demands may not provoke the adapted movement patterns that have been linked to the athletic or occupational demands and potential injuries of interest. Therefore, the objective of this study was to examine the impact of load and speed on individuals' movement behaviors. It was hypothesized that the adaptations observed would be individual and demand specific.

Methods

Experimental Approach to the Problem

A repeated measures study design was used to evaluate the influence of load and movement speed on participants' execution of 5 whole-body tasks. Professional firefighters were recruited to participate in a larger training study (12), which included the performance of 5 low-demand (i.e., light load, low movement speed) general whole-body tasks. The tasks were performed in random order, and chosen to replicate a fundamental movement pattern (i.e., lift, squat, lunge, push, and pull). At no time were the objectives of the evaluation or the study hypotheses discussed with the participants. Instead they were asked to perform the battery of tasks as part of the preintervention evaluation for the training study mentioned above (12). Once each task had been performed, its demands were modified in 3 ways: (a) increased movement speed (through instruction), (b) increased external load, and (c) increased movement speed and external load. Select measures of joint and body segment motion were used to characterize the performance of each task and comparisons were made between conditions.

Subjects

Fifty-two male firefighters from the Pensacola Fire Department participated in this investigation. All the men were free of musculoskeletal injury at the time of testing and 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, each approved the investigation, and all the participants gave their informed consent before the data collection began.

Task Selection

Five tasks were chosen to reflect commonly performed whole-body movement patterns. The tasks were (a) Lift–from standing, individuals lifted a box ($0.33 \times 0.33 \times 0.28$ m) from the ground to waist height; (b) Squat–from standing, individuals performed a bodyweight squat (depth was self-selected); (c) Lunge–from standing, individuals lunged forward onto their right leg and returned to the starting position; (d) Push–from a staggered stance (left leg forwards), individuals performed a cable press with the right arm; and (e) Pull–from a staggered stance (left leg forwards), individuals performed a cable pull with the right arm.

Procedures

The participants were instrumented with reflective markers and familiarized with the tasks using a standard set of instructions. To examine the impact of load and speed on individuals' movement behaviors, each general task was performed with 4 load and speed combinations. The initial exposure to each task reflected a low-demand scenario, wherein the external load and speed of movement were low (low load, low velocity). The lifting trials were performed with 6.8 kg, the squats and lunges were completed with bodyweight, and the push and pull loads were set at 4 and 6.5 kg, respectively. The tasks were performed in a randomized fashion (3 repetitions each) and approximately 15- and 60-second rest was given between each trial and task, respectively, to attenuate the potential for fatigue. Once all tasks had been completed, the movement speed and external load were modified in 3 ways: (a) low load, high velocity–increase in movement speed only; the participants were asked to complete each trial as fast as was comfortable; (b) high load, low velocity–increase in external load only; 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 set at 9.8 and 13.6 kg, respectively; and (c) high load, high velocity–increase in movement speed and external load. The research question investigated did not necessitate that the participants perform to their maximum ability. Instead, we sought to explore the influence of load and speed (submaximal) on participants' movement behaviors. Each condition was performed sequentially based on the expected musculoskeletal demands, such that systematic comparisons could be made across the 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. No feedback was given regarding task performance at any point throughout the investigation. Compression shorts, a tight t-shirt, and athletic shoes were worn at all times.

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 define the proximal and distal endpoints of the trunk, pelvis, thighs, shanks, and feet. The participants' hip joint centers and knee joint axes were determined "functionally" using methods similar to those described by Begon et al. (2) and Schwartz and Rozumalski (32). Briefly, the participants were asked to perform 10 repetitions of "hula-hooping" (closed-chain hip circumduction) and standing open-chain knee flexion and extension for the hip and knee joint computations, respectively. Visual 3D software (Version 4; C-Motion, Inc., Germantown, MD, USA) was used to calculate the axis of rotation between every pair of measured adjacent segment configurations. The most likely intersection and orientation of the axes were used to define the effective joint centers and joint axes, respectively. Using functionally defined segment endpoints for the shank and thigh has been shown to minimize the variation introduced through bony palpation (or digitization), and thus provide a more stable way to create each individual's rigid link segment model (14). 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 3-dimensional space. One standing calibration trial was collected such that the orientation of each segment's local axis system could be determined through a transformation from an axis system embedded within each rigid body. The anatomical markers were removed once the calibration procedures were completed. The marker data were collected at 160 Hz and smoothed with a low-pass filter (6 Hz).

Statistical Analyses

The participants' movement patterns were characterized with 9 variables, each chosen to reflect a possible mechanism for injury (e.g., spine motion) (4,26) or a coaching observation commonly used to characterize individuals' performance (e.g., trunk angle) (23). Although these observations have not been cited as mechanisms for injury, each has been listed previously as a possible risk factor (25,31) or shown to influence the knee, hip, or low back movements, while squatting (15,23) or lifting (34). The 9 variables were (a–c) spine flexion and extension (FLX), lateral bend (BND), and axial twist (TST)–the relative orientation of the trunk was expressed with respect to the pelvis and the corresponding direction cosine matrix was decomposed with a rotation sequence of flexion and extension, abduction and adduction, and axial rotation (6) to compute the spine angle about each axis. The orientation of the spine in a relaxed upright standing trial was defined as zero degrees; (d) trunk angle (TRK) relative to the vertical–the relative orientation of the trunk (flexion and extension only) was expressed with respect to a pelvis segment that was free to move with the body, but constrained about the flexion and extension axis, thereby remaining upright; (e) shank angle (SHK) relative to the vertical–the relative orientation of the left and right shank (flexion and extension only) was expressed with respect to the upright pelvis; (f) hip to ankle distance (HIP)–using the upright pelvis mentioned previously to define a body-fixed anterior/posterior (A/P) axis, the position of each hip joint in the A/P direction was described relative to the same side ankle; (g) knee to ankle distance (KNE)–the position of each knee joint in the A/P direction was described relative to the same side ankle; and (h,i) 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. The SHK, HIP, and KNE variables were only computed for the lead leg of the lunging (right), pushing (left), and pulling (left) tasks and defined as an average of the left and right sides for lifting and squatting.

To objectively define the start, midpoint, and end of each trial, event detection algorithms were created in Visual 3D by tracking the motion of the trunk, pelvis, right forearm (push and pull), and whole-body center of mass. Each task was separated into 2 phases; a descent and ascent for the lifting, squatting, and lunging tasks, and a "toward" and "away" from the body (in reference to the motion of the right forearm) for the push and pull. To verify that events were defined as intended, model animations of all the trials were inspected visually. Maximums, minimums, and means were computed for the 9 dependent variables (each phase separately). The "peak" of each variable, with the exception of BND and TST, was described as the deviation (maximum or minimum) hypothesized to be the most relevant to the characterization of each pattern (i.e., FLX–flexion, TRK and SHK–forward bend, HIP–posterior displacement, KNE–anterior displacement, LFT and RGT–medial displacement). Peak BND and TST were described as the range (i.e., max-min) observed for the specified phase.

The 3-repetition means for each condition were used to examine the influence of the load and speed on each dependent measure. Comparisons were made using a general linear model with 2 repeated factors (IBM SPSS Statistics, Version 20.0, Armonk, NY, USA). Significant main effects and load × speed interactions were described by a $p \leq 0.05$.

Within-Subject Differences. Subject-specific responses for those variables cited as possible mechanisms for injury (FLX, BND, TST, LFT, and RGT) were examined for each task. The mean of both light load conditions (i.e., low and high velocities) was compared with that of the high-load conditions and the difference score was normalized by the maximum within-subject variation (group average) $\pm 1SD$ observed for the maximum, minimum, or mean of any condition for that variable. A score >1 or <-1 implied that the load effect was greater than the variation observed within participants $\pm 1SD$, and was defined here as a clinically relevant or "meaningful" difference (12). This same process was repeated to examine the impact of speed; the mean of both low-velocity conditions (i.e., low and high loads) was compared with that of the high-velocity conditions, and the difference scores were normalized by the within-subject variation used previously. As such, the same difference score was used to define a meaningful subject-specific response with regard to changes in the load or speed of movement.

Results

Significant main effects of load and speed were noted for several variables (Table 1); however, each dependent measure was not influenced to the same degree or in the same manner across the 5 tasks being investigated, nor were they affected by changing the external load and movement speed in the same way. For example, when the participants performed the lifting task with a heavier load, they adopted a more upright trunk posture, which was characterized by a decrease ($p = 0.007$) and increase ($p = 0.038$) in their peak trunk and shank angles, respectively. Increasing the speed of movement, however, prompted the opposite response; the participants were found to use a more "hip-dominant" pattern, whereby their hips and knees were shifted backward ($p = 0.038$ and $p = 0.036$ for peak HIP and KNE, respectively). Similar adaptations were observed when the squat was performed with a higher load and speed (i.e., load–hips

Table 1. A summary of all the main effects and interactions (load × speed) for the LFT, SQT, LNG, PSH, and PLL tasks.*†‡§||

		Phase 1										Phase 2									
		Peak					Mean					Peak					Mean				
		LFT	SQT	LNG	PSH	PLL	LFT	SQT	LNG	PSH	PLL	LFT	SQT	LNG	PSH	PLL	LFT	SQT	LNG	PSH	PLL
Load	FLX		#	↑	#			#	↑	↓	↑		#	↑				#	↑	↓	↑
	BND	N/A	N/A		↑	↑	N/A	N/A	↓	#	#	N/A	N/A		↑	#	N/A	N/A		↑	↑
	TST	N/A	N/A	↓	#	#	N/A	N/A		↓	↑	N/A	N/A		↑	#	N/A	N/A	↓	#	↑
	TRK	↓		↑	↑	↑			↑	↑	#	↓	#	↑	↑	#		#	↑	↑	↑
	SHK	↑		↑	↑		↑		#	↑	↑			#	↑		↓		#	↑	
	HIP		↓			↑		↓	#		#	#	#			#	↑	↓	#		#
	KNE			↑	↑		↑		#	↑	↓			#	↑		↓		#	↑	
	LFT			N/A	#	↑			N/A	↕		#		N/A	↓		#		N/A	↓	
	RGT	#		↓	N/A	N/A		#	#	N/A	N/A	#		↓	N/A	N/A			↓	N/A	N/A
Speed	FLX		#	↑	#	↑	↓	#	↑	↓	↑		#	↑	↑	↑		#	↑		↑
	BND	N/A	N/A	↑	↑	↑	N/A	N/A		#	#	N/A	N/A	↑	↑	#	N/A	N/A	↑	↑	↑
	TST	N/A	N/A	↑	#	#	N/A	N/A		↑		N/A	N/A	↑	↑	#	N/A	N/A		#	↓
	TRK			↑		↑		↓	↑		#		#	↑		#	↑	#	↑	↑	↑
	SHK		↓	↑	↑	↑		↓	#	↑	↑		↓	#	↑	↑			#	↑	↑
	HIP	↑	↑	↑		↑			#		#	#	#	↑		#			#		#
	KNE	↓	↓	↑	↑	↑		↓	#	↑	↑		↓	#	↑	↑			#	↑	↑
	LFT			N/A	#	↑		↓	N/A	#	↑	#		N/A		↑	#		N/A	↓	↑
	RGT	#			N/A	N/A		#	#	N/A	N/A	#			N/A	N/A				N/A	N/A

*FLX = spine flexion and extension; BND = spine lateral bend; TST = spine twist; TRK = trunk angle; SHK = shank angle; HIP = hip to ankle distance; KNE = knee to ankle distance; LFT = left knee position; RGT = right knee position; LFT = lift; SQT = squat; LNG = lunge; PSH = push; PLL = pull.

†Results for the peaks and means of each phase (e.g., descent and ascent) are presented.

‡Significant main effects ($p \leq 0.05$) are highlighted by a ↑ or ↓; the direction indicates whether more or less motion was observed after an increase to the demands.

§Significant interactions ($p \leq 0.05$) are marked with a "#."

||N/A signifies not computed.

forward [$p < 0.001$ and $p = 0.025$ for peak HIP and KNE, respectively]; speed–hips backward [$p < 0.001$ and $p = 0.089$ for peak HIP and KNE, respectively]). For the lunge, push, and pull, the load and speed were found to have a comparable influence on participants' movement patterns, albeit dissimilar for each task. The lunges were performed with more spine flexion ($p < 0.001$; means and peaks), a greater trunk lean ($p < 0.001$; means and peaks), and an anterior shift of the knee ($p \le 0.05$; means and peaks). Pushing and pulling were both characterized by an increase in BND ($p < 0.01$) and forward trunk lean ($p < 0.001$), but although the participants sat back (i.e., increase in HIP; $p < 0.001$) during the higher demanding pull trials, they exhibited a forward shift (i.e., increase in KNE; $p < 0.001$) when pushing.

The subject-specific adaptations to an increased load are illustrated in Figure 1. Substantial variation was observed in the magnitude and the direction of the responses observed among participants. Most were smaller in magnitude than the within-subject variation (i.e., "meaningful" change); however, with the exception of LFT for the pushing tasks, at least

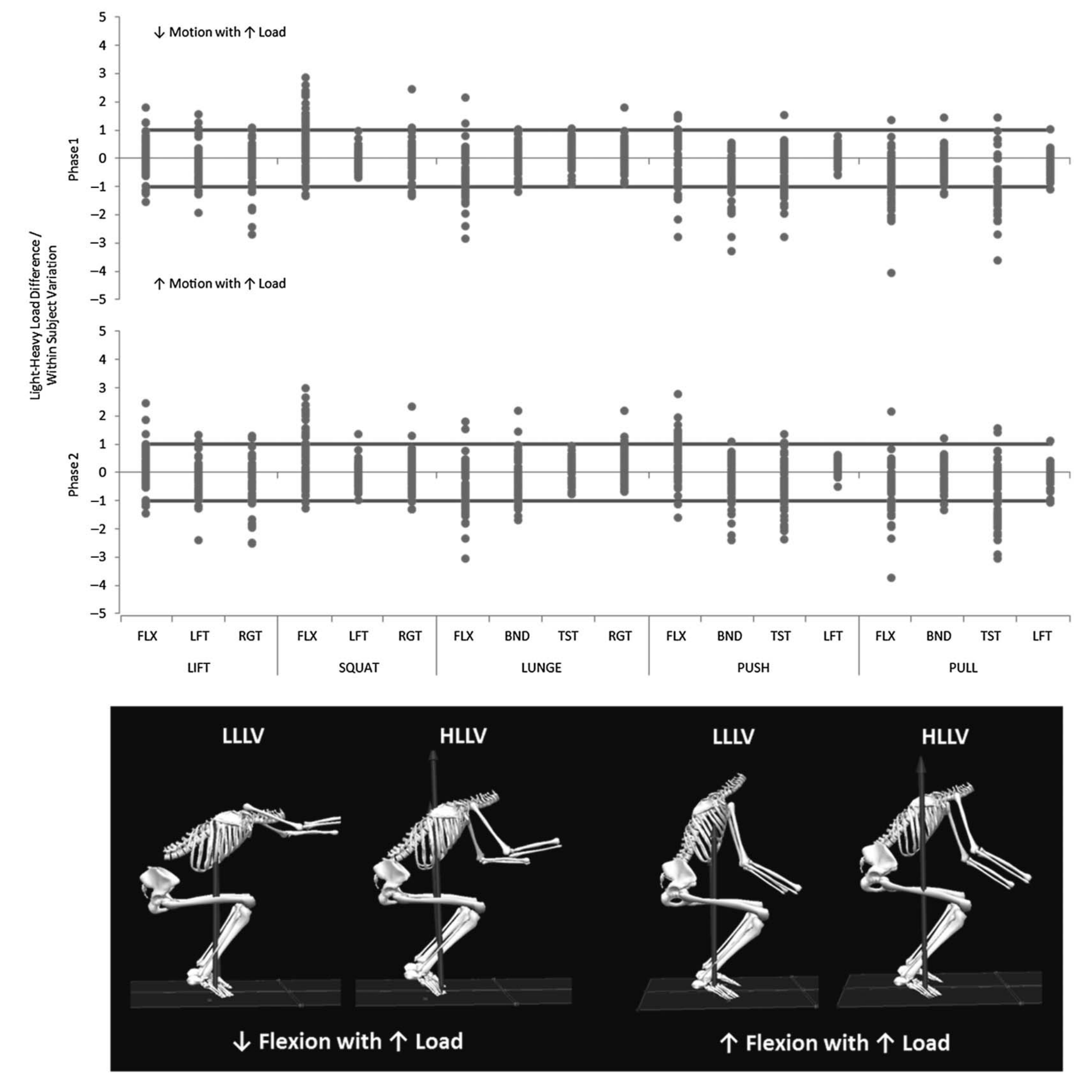

Figure 1. Individual responses (circles, $n = 52$) in spine and knee motion to an increase in the load. The mean of the low- (low and high velocities) and high-load conditions were compared, and the difference score was normalized by the maximum within-subject variation $\pm 1SD$ observed for any metric (i.e., max, min, or mean) or condition of a particular variable (e.g., spine flexion and extension) and task. The data presented represent the differences in the peak of each variable and phase (e.g., descent and ascent). The solid lines denote a difference score equal to the within-subject variation $\pm 1SD$. The values outside these boundaries were described as clinically relevant changes. A positive response implies a decrease in motion with an increase in the load. The model animations (squat) for 2 participants provide a visual depiction of the variation observed in spine flexion, trunk posture, and the hip and knee positions. FLX = spine flexion and extension; LFT = left knee position; RGT = right knee position; BND = spine lateral bend; TST = spine twist.

1 firefighter did exhibit a biologically significant change in the positive (less motion) and negative direction (more motion) for every dependent measure. This finding highlights the fact that although there were significant load effects seen for the group, the mean adaptations did not reflect the movement behaviors exhibited by all individuals. There were more participants who demonstrated an increase in spine and frontal plane motion when the load was elevated (125 vs. 39 and 113 vs. 55 for phases 1 and 2, respectively).

Similar subject-specific adaptations were seen when the speed was increased (Figure 2); however, in contrast to the single case cited above, there were 7 instances wherein at least 1 participant did not exhibit a positive meaningful change; LFT for squatting, FLX for lunging, BND, TST, and LFT for pushing, and TST and LFT for pulling. Generally, increasing the movement speed had a greater negative effect on the spine and frontal plane knee motion, in comparison with increasing the load–the total number of meaningful negative and positive changes observed in response to

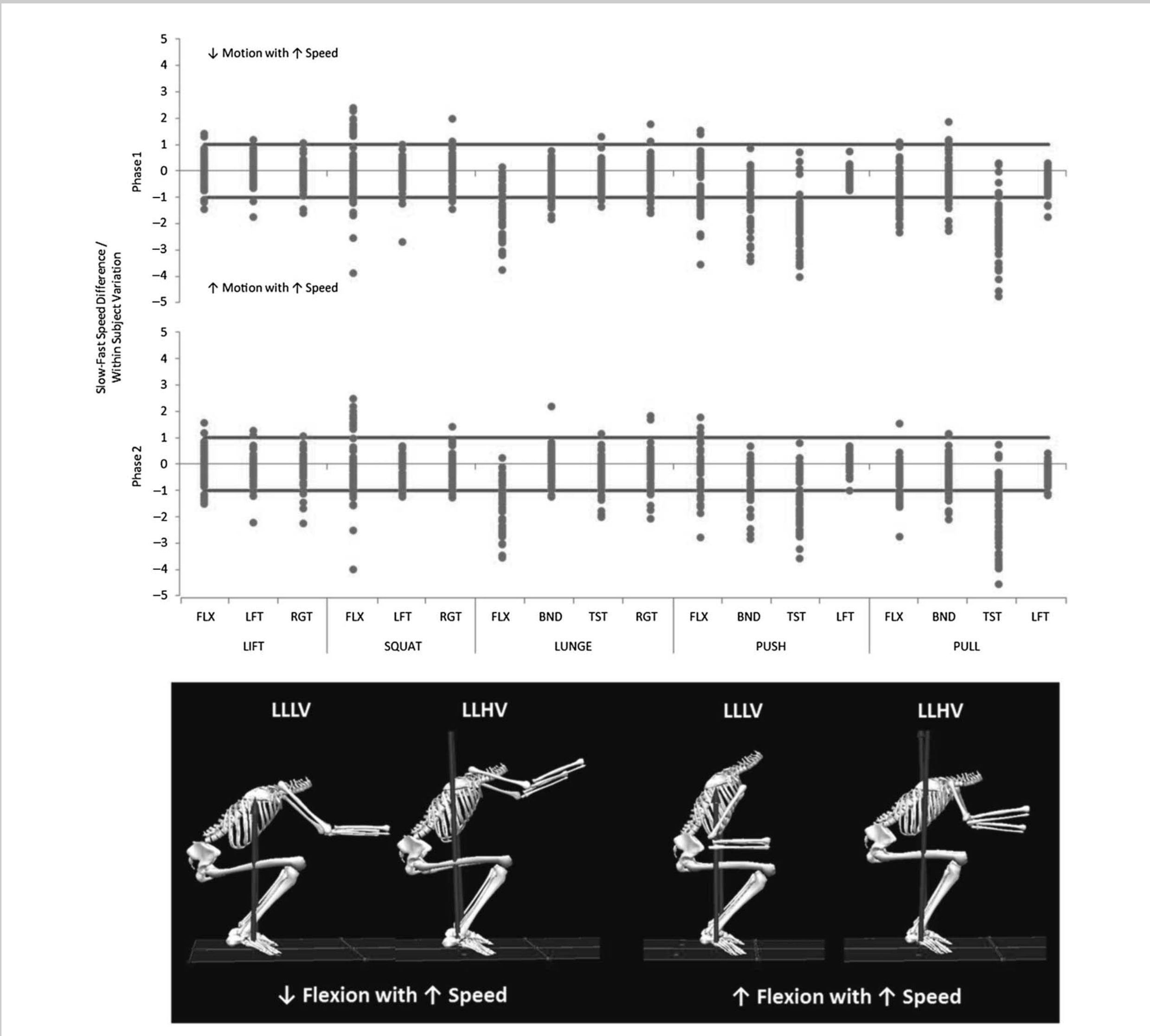

Figure 2. Individual responses (circles, $n = 52$) in spine and knee motion to an increase in speed. The means of the low- (low and high loads) and high-velocity conditions were compared, and the difference score was normalized by the maximum within-subject variation $\pm 1SD$ observed for any metric (i.e., max, min, or mean) or condition of a particular variable (e.g., spine flexion and extension) and task. The data presented represent the differences in the peak of each variable and phase (e.g., descent and ascent). The solid lines denote a difference score equal to the within-subject variation $\pm 1SD$. Values outside these boundaries were described as clinically relevant or changes. A positive response implies a decrease in the motion with an increase in speed. The model animations (squat) for 2 participants provide a visual depiction of the variation observed in spine flexion, trunk angle, and the hip and knee positions. FLX = spine flexion and extension; LFT = left knee position; RGT = right knee position; BND = spine lateral bend; TST = spine twist.

an increase in speed were 246 vs. 25 and 201 vs. 27 for phases 1 and 2, respectively. Also, of note, was the finding that of the 52 participants, 20 exhibited a meaningful change in FLX while squatting; 10 improved and 10 got worse, thus making it difficult to make any general conclusions or group recommendations.

Discussion

Given the links between individuals' movement patterns and their risk of future injury and the popularity of movement evaluations, this investigation sought to explore the impact of load and speed on individuals' movement behaviors. It was hypothesized that if individuals adapt the way they move in response to the demands of a task, the utility of evaluations comprising only low-demand activities could have limited application. The findings of this investigation do provide support for the notion that individuals adapt their movement patterns in response to the demands of a task; however, perhaps more intriguing was the fact that the adaptations observed were quite variable among participants, and often specific to the task or type of demand in question.

Faced with the seemingly simple task of lifting a box from the ground, the group adapted their movement behaviors in response to an increase in load. The trunk angle (i.e., lean) was significantly lower during the heavy trials, even during the descent phase before the load was placed in the hands. Whether or not the participants made a conscious decision to change, an upright trunk posture is often perceived as one of the most effective solutions to accommodate an elevated demand while lifting, because it affords a better opportunity to "lift with your legs and not with your back." But, lifting with an upright trunk does not guarantee that a neutral lumbar spine curvature will be maintained, nor does it imply that less mechanical work will be done by the low back moment. It does, however, make it difficult and possibly unnecessary to engage the hip extensors given that the hip moment demands are attenuated when the joints are positioned directly beneath the trunk and over the base of support. As a result, choosing to lift "…not with the back" may have little impact on the risk of sustaining a low back injury (spine curvature may be critical) and could inadvertently increase the demand imposed on the knees. Interestingly, the participants exhibited an opposing movement strategy to accommodate the increase in speed: the hips and knees were positioned further backwards (i.e., a more "hip-dominant" strategy) and they increased their forward trunk lean.

Given the lack of homogeneity within the group, it would be inappropriate to speculate as to a single reason why the participants responded differently to the high-speed lifting trials. However, the possibilities are intriguing given that a similar response was noted for the squat. Instructing the firefighters to perform as fast as was comfortable may have shifted their attentional focus (23,36) from their body posture and motion during task execution (i.e., internal focus) to the speed at which it was performed (i.e., external focus), perhaps causing them to ignore any preconceived ideas regarding the most effective or safest way to move (30). They no longer focused on how the task was executed, but instead shifted their attention to how fast they were performing. In comparison, it is unlikely that the instruction to "lift the heavy box" would have had the same influence on the participants' focus of attention, unless the load was of a magnitude that required a maximal or supramaximal effort. Faced with the fear of failing to perform, the participants might shift their attention to the load being lifted and away from the way they move, if in fact they were consciously considering their movement strategies in the first place. Numerous studies have shown that shifting an individual's focus of attention can influence movement outcomes (30). Alternatively, the firefighters may have simply found it easier to lift and squat quickly when they adopted a more hip dominant strategy. If the hips are positioned posteriorly, less effort will be required by the extensors of the knees, which consequently will also reduce the joint loads and perhaps the potential for injury. When the trunk is kept upright, it also becomes very difficult to squat or lift to any substantial depth while keeping the heels on the ground, hence the toe squatter response. The participants adopting this movement strategy during the slow trials may have found it too difficult to perform quickly with a smaller base of support.

The lunge trials were executed by displacing the body's center of mass in the anterior and posterior and vertical directions, which, for most participants, would have increased their body's momentum and thus the level of effort and coordination required, in comparison with performing a lift or squat. Firefighters lacking the awareness or understanding needed to perform safely and effectively would be expected to exhibit a movement behavior indicative of these additional demands (e.g., uncontrolled forward motion), particularly during the transition from the descent to the ascent phase when the effort required is highest. Changing the lunge's demands through an increase in load or speed would simply make it even more challenging to control the body's forward momentum. This is precisely what the group's adapted behavior looked like in response to the elevated demands; they showed significantly ($p \leq 0.05$) more lumbar spine flexion, a forward trunk lean, and an anterior shift of the knee. Because the load was increased through a weighted vest, the participants may have found it more difficult to control their trunk because of the increased core and whole-body stability demands. However, it is also possible that the changes were planned and made in preparation to "throw" their trunks backward to assist with the ascent phase.

The increase in lateral bend exhibited by the group in response to elevating the push and pull loads and speeds can be rationalized using similar mechanical principles to those of a single arm push-up. Resisting lumbar spine rotation during a bilateral push-up is relatively simple, because forces are applied to the ground on either side of the body's midline; each arm offsets the rotational demands created by placement of the other. However, if 1 arm were raised, the individual's ability to avoid motion in the transverse plane would be challenged because of the single off-center force now imposing a rotational demand on the body. The farther the hand is from the midline, the more challenging the task becomes. This is why, if asked to perform a single arm push-up, individuals accommodate by shifting their upper body over their hand.

The groups' adapted movement behaviors could be rationalized for each task using the fundamental principles of biomechanics, but each participant was also different, and thus likely changed their movement patterns for a variety of reasons. There were certainly individuals who exhibited a similar response to that of the group; however, at least 1 firefighter was found to exhibit a biologically significant or meaningful adaptation in either direction (positive or negative) for all but 1 variable investigated. Therefore, evaluating a specific ability (e.g., flexibility) or seeking to establish an individual's risk of future injury could be quite difficult if the individual's task performance is influenced by several factors including their perception of risk, appreciation for the task's objectives, focus of attention, previous experiences, or body awareness (10,13,27,28,30). Assuming that someone moves in a given manner because of any 1 factor is likely inappropriate in most settings because it could adversely affect the interpretation of the observations and misdirect any recommendations being made to improve their safety or effectiveness.

From a mechanical perspective, tissues fail when their tolerance is exceeded by the applied load. If an individual's movement patterns are being evaluated to establish risk or personalize recommendations to prevent the occurrence of future problems, it will likely be important to first identify the possible mechanisms for the injuries of interest so that key features of the motion pattern can be used as criteria with which to describe a movement as "good" or "bad." For example, injuries to the lower back, knees, and shoulders are commonly sustained by firefighters (19), which suggests that adopted patterns such as uncontrolled spine and frontal plane knee motion may be critical observations. Obviously, the demands of the task will influence the applied load and therefore the potential for sustaining an injury; however, this approach could provide a framework with which to categorize individuals' responses to varying demands while accommodating the potential interaction between ability, awareness, and understanding. The exact reason as to why the movement pattern was exhibited may not be as important as noting its presence, at least initially, given that simply providing feedback, coaching, or asking whether the individual was aware may alleviate the issue.

Practical Applications

As has been highlighted by the results of this investigation, individuals adapt their movement behavior in response to elevated external task demands. Whether because the additional challenges provoked a sense of risk motivating the adoption of a safer and more effective (perceived) pattern, or was of a magnitude that exceeded some aspect of their capacity thus causing undesirable joint motion, the information gained by evaluating movement can provide a valuable insight into assisting in making future recommendations for training. But the data also suggest that movement evaluations comprising only low-demand activities may not adequately reflect an individual's risk of injury, and could adversely affect any recommendations being made for training. Simply because an individual exhibits the ability to perform a low-demand activity with competence, does not imply that they will also be physically prepared to perform safely or effectively when a task's demands are increased, nor does it imply the opposite. Having superior strength will provide a greater opportunity to perform a high-intensity activity, just as muscular endurance will assist when a task's duration is extended, but these physical attributes only reflect potential. Other factors such as the perception of risk, awareness, and coordination can also influence the way that an individual moves and thus any adaptations observed in response to a change in demands will likely be quite variable among a group, and specific to the task or type of demand in question. As a result, when evaluating a client's movement patterns, it may be advantageous for strength and conditioning professionals to use a range of loads, speeds, repetitions, times, etc., such that their observations can directly influence any recommendations being made for training. Exercise could then be viewed as a means to elevate the magnitude of demands (e.g., load and speed) at which the client exhibits desirable movement behaviors, through changes to their ability, understanding, or awareness.

Acknowledgments

The authors are grateful to Athletes' Performance and the Andrews Research and Education Institute for the use of their facilities. The authors would also like to extend their gratitude to each member of Pensacola Fire Department for their commitment to this work. Funding for this project was provided by the Center of Research Expertise for the Prevention of Musculoskeletal Disorders and the Natural Sciences and Engineering Research Council of Canada. Jack P. Callaghan is supported by the Canada Research Chair in Spine Biomechanics and Injury Prevention.

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