

A Relation Between Dynamic Strength and Manual Materials-Handling Strategy Affected by Knowledge of Strength

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Objective: We studied the relation between dynamic (isokinetic) strength and the batch-assorting strategy to initiate a manual materials-handling task and the effect of knowledge of strength on that relation. **Background:** The debated, complex relationship between muscular strength and the risk of injury can be better understood from a behavioral perspective by examining performance strategies in physical acts such as lifting. **Methods:** Thirty-two participants (16 men and 16 women) were first tested for their isokinetic strengths of trunk extension, knee extension, shoulder extension, and shoulder abduction. The participants were then divided into two groups, one provided with knowledge feedback of their strength testing results and the other not provided with such feedback. Participants subsequently performed the same load-handling task in which they carried batches of various weight plates while allowed to assort batches of more than one plate into any combination. **Results:** Dynamic strength, as represented by a total isokinetic strength score, and knowledge feedback both had significant effects on measures quantifying the batch-assorting strategy. **Conclusion:** Individuals with greater strength tended to adopt a strategy corresponding to a heavier load per carry and fewer carries per batch. Receiving knowledge feedback evoked a tendency toward handling a heavier load, and this tendency was more salient in the weaker individuals. **Application:** Potential applications include the use of strength testing in worker selection and training as well as in job design to promote better strategies of balancing productivity and injury prevention.

INTRODUCTION

Despite advancements in the automation of materials handling, many tasks still must be carried out manually. Overexertions during manual materials-handling tasks in the workplace can significantly elevate the risk of musculoskeletal disorders or injuries. According to the Bureau of Labor Statistics, in 2002 more than 200,000 injuries resulted from overexertion while lifting and nearly 60,000 others were attributable to overexertion in holding, carrying, or turning objects (Bureau of Labor Statistics, n.d.). Manual materials-handling tasks vary widely, as do individuals' physical capacities. Because of this dual variability in the demand-capacity match, accounting for the

variables that constitute a manual materials-handling task and investigating their effects on performance is important (Chaffin, Andersson, & Martin, 1999).

Muscular strength as a major physical capacity variable has long been suggested as a determinant in the performance of manual materials handling and associated injury risk. Attributes including strength and endurance have been shown to affect the ability and efficiency of manually handling materials (Herrin, Chaffin, & Mach, 1974). Isokinetic strength in particular has been found to correlate with lifting ability in healthy men (Wilmarth & Herekar, 1991). Cady, Bischoff, O'Connell, Thomas, and Allan (1979) rated the fitness of 1652 firefighters, defining *fitness* as a combination of

measures of endurance, strength, flexibility, blood pressure, and heart rate recovery. They observed that individuals with high levels of fitness incurred fewer back injuries than did those with low levels of fitness, and the injuries sustained tended to be less costly for the fittest in the group. Nicholson and Legg (1986) also noted that weaker individuals were more likely to sustain exertion-related injuries. Longitudinal studies by Chaffin and associates (Chaffin, Herrin, Keyserling, & Foulke, 1977; Chaffin & Park, 1973) suggested that weaker individuals could be three times more likely to suffer back injuries on the job than stronger individuals.

However, the relationship between muscular strength and risk of injury is a complex one. This is particularly true when there are alternatives to complete a task, allowing different strategies, self-protective or otherwise, to be adopted. Under such circumstances, a multitude of factors can influence people's decision making and selection of strategies or actions. For instance, it is recommended that workers verify the heaviness of a load before handling it in order to reduce the risk of injury (Genaidy et al., 1998), but this verification process is influenced by a variety of task factors (see Karwowski et al., 1999, for a discussion of these factors). In Ciriello and Snook (1983), it was observed that several factors can affect the perception of acceptable weights, including the size of the object, the distance it must be lifted, and how frequently it must be lifted. Karwowski and Yates (1986) corroborated that the perception of ability when lifting self-selected loads is influenced by the frequency of the lift. Nicholson and Legg (1986) allowed young men to vary their lifting load and pace in determining a maximum acceptable workload; they concurred that the pace and load had effects, but they concluded that the maximum acceptable workload is affected primarily by factors that are not physiological.

Additional studies have also examined the effects of non-task-related or personal variables on individuals' perceptions about their lifting abilities. Jackson and Sekula (1999) reported that, given strength-matched groups of men and women, the women perceived lifting the same load as more difficult. Further, Brownsword (1987) found that some individuals' personalities could compel them to perform tasks at a level corresponding to the perceived competition from individuals around them. It has also been demonstrated that the ex-

perience one possesses may influence the amount of weight that they choose to lift (Mital, 1987). Bandura (1986) stated that extrinsic feedback would affect the way individuals carry out tasks and might especially influence competency judgments in unfamiliar tasks. Ryan, Greguras, and Ployhart (1996) found that if a physical aptitude test is not closely related to the actual task, then participation may be affected by individuals' judgments of the test as a fair evaluative measure.

A search in the literature nevertheless did not identify any study that investigated a relationship between strength (particularly dynamic or isokinetic strength) and manual materials-handling strategy and how that relationship can be modulated by self-perception or knowledge of the strength. Many manual materials-handling tasks, particularly repetitive ones such as palletizing, allow some flexibility in the method of completion. In these situations individuals must rely on their perceptions of the task demand and of their ability in order to choose a strategy. So when some flexibility exists in how a manual task can be completed – for instance, the pace or load handled per action – will stronger and weaker individuals adopt different strategies? Will people's choices, and consequently their injury risks, be influenced by their self-perception and more accurate knowledge of their own strength?

The current study aimed to address these questions. Specifically, this study investigated how dynamic (isokinetic) strength and knowledge feedback influence the batch-assorting strategy during a manual materials-handling task. Here, *knowledge feedback* refers to knowledge of dynamic strength testing results and *batch-assorting strategy* refers to how many carries one elects to take in completing a handling task for which the size of a batch (i.e., the total number of load items) is specified.

METHODS

Participants

Thirty-two participants, 16 men and 16 women, were recruited from the university community. The participants' mean weights and heights ($\pm SD$) were 79.52 (± 15.62) kg and 181.61 (± 8.85) cm for the men and 61.80 (± 11.35) kg and 165.26 (± 7.33) cm for the women. Participants ranged in age from 20 to 41 (average 24.28 ± 5.36) and were free of any chronic pain or disorder at the time of

the experiment. It was assumed that in this study the participants represented a broad cross section of relatively young and healthy individuals. The participants were advised that their involvement was voluntary and that they could discontinue their involvement at any time. Informed consent was obtained from each participant. The experimental protocol was approved by University of Illinois Institutional Review Board.

Experimental Procedure

Each participant took part in two sessions on two different days of the experiment. The first session involved testing the participants' dynamic (isokinetic) strengths on a Biodex System 2 dynamometer (Biodex Medical Systems, Shirley, NY). Seven joint strengths were tested: back (trunk) extension, right and left knee extensions, and right and left shoulder extensions and abductions. The joint rotation speed was controlled at 60°/s for all the tests. The back extension was completed first, followed by the knee extensions, and then by shoulder extensions and abductions. Dominant limbs were tested first in the bilateral tests, and participants performed submaximal warm-ups before the tests. Each test entailed completing three sets of five repetitions for each joint-direction combination. Participants were provided with a rest period of approximately 90 s between sets to minimize fatigue effect, according to the findings of Parcell, Sawyer, Tricoli, and Chinevere (2002). Figure 1 shows a participant at the beginning of a back extension test.

The range of motion settings for the tests were as follows: 100° to 150° for back extension, 0° to 90° for knee extension, and 0° to 90° for shoulder extension. The lower limit of the range of shoulder abduction varied by individual (generally between 9° and 22°) because of potential interference from the seat of the Biodex unit. Narrower shoulders, therefore, produced greater minimum angles than did wider shoulders; the upper limit of the range was 90°.

Maximum torque values from each joint-direction test were obtained and summed over the seven joint-direction combinations to generate a total isokinetic strength (TIS) value. Participants were then divided into two groups (Groups A and B) of 16, with each group composed of 8 men and 8 women. Participants were sorted such that the strength differences between the two groups were minimized. The differences in TIS values

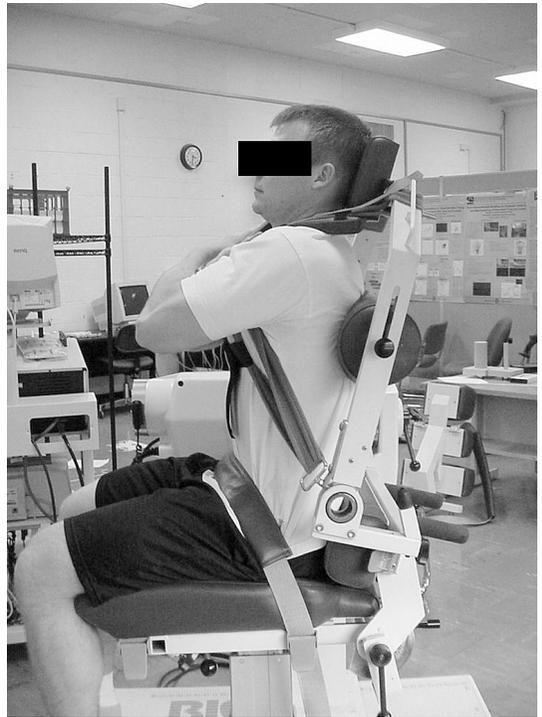


Figure 1. A participant secured into the trunk extension/flexion attachment utilized in the testing of isokinetic back extension strength.

between the two groups were statistically insignificant according to a *t* test ($p = .898$); the differences in mean strength values for individual joints were also found to be insignificant (p values ranged from .429 to .979).

Prior to beginning of the second session, the participants were asked to estimate their overall strengths relative to the general population by placing a mark on a graduated scale (see Figure 2). Following that, Group A participants were given feedback on their strengths relative to other participants in this study. This feedback included strength scores (torque values), percentiles within their gender, and percentiles among all participants for the seven individual joint maximum torques as well as the TIS values recorded in the first session (see Table 1). The feedback was presented using the same graduated scale (Figure 2) along with verbal explanations by an experimenter to each participant individually. Group B participants were not provided with any feedback concerning their strength test results. Both groups subsequently performed the same manual materials-handling task in the second session.

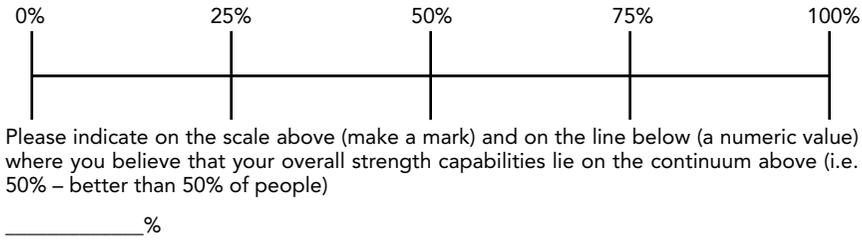


Figure 2. The scale upon which participants indicated their prediction of their overall strength relative to the general population.

The manual materials-handling task required participants to transfer batches of plates in a 36- (width) × 38- (depth) × 28-cm (height) crate. The plates were identical and weighed 5 pounds (2.27 kg) each. Participants were not informed of the weight of the plates. They each completed 12 trials – six batches consisting of one through six plates and two replications – in a completely randomized order and at a self-preferred pace. Participants were allowed to assort a batch of more than one plate into any combination. For example, for a batch of three plates, a participant could choose to transfer all three in one carry, two in one carry and one in the other, or one in each of three carries. The number of plates transferred in each carry was recorded. Participants were allowed to rest at any time between carries and were reminded after every third batch that they could rest.

Analysis

Analysis of recorded strength data was completed, and comparisons with previously published dynamic strength data were made. The correlations of joint strengths were inspected. Differences be-

tween participants’ own estimated strengths in terms of percentile ranks relative to the general population and the actual percentile ranks were examined. Two measures, the average number of carries per batch of *n* plates (ACB_{*n*}) and the average load per carry (ALC) across the batches of 4, 5, and 6 weights were defined in order to quantify the material-handling strategies adopted by the participants. Because of the discontinuous nature of ACB_{*n*} and ALC, a logistic regression was performed (Stokes, Davis, & Koch, 1995) to analyze the association of TIS with ACB_{*n*} and ALC, and to examine the effect of knowledge feedback. A term was included in the logistic regression model to examine the interaction of TIS and gender. Note that because there was little variation in ACB_{*n*} and ALC for batches of one, two, and three plates, they were omitted from the analysis.

RESULTS

The minimum and maximum TIS scores recorded were 286 N·m and 1161 N·m, respectively. The TIS values formed a normal distribution

TABLE 1: An Example of the Table Presenting Strength Testing Results to Group A Participants

Strength Test	Results		
	Max. Torque (N·m)	Percentile	
		Within Gender	Within All Participants
Back extension	267	53	71
Shoulder abduction (L)	47	27	61
Shoulder abduction (R)	49	20	58
Shoulder extension (L)	56	33	68
Shoulder extension (R)	62	33	68
Knee extension (L)	130	27	48
Knee extension (R)	132	13	42
Total isokinetic strength	743	20	48

TABLE 2: Summary of the Isokinetic Strengths Values for Men, Women, and Both Genders Combined

Gender	Joint Strengths (N·m)				
	Back Extension	Shoulder Abduction ^a	Shoulder Extension ^a	Knee Extension ^a	TIS
Men	283 ± 76	57 ± 11	64 ± 12	160 ± 40	844 ± 177
Women	198 ± 61	32 ± 8	34 ± 7	106 ± 43	543 ± 164
Both	240 ± 80	45 ± 16	49 ± 18	133 ± 49	694 ± 227

^aLeft and right sides averaged.

according to a Shapiro-Wilkes test for normality ($p = .3399$). Participants in this study had lower strength scores in most tests as compared with isokinetic strength data available in the literature (Dvir, 2004; Perrin, 1993). A statistical summary of the individual joint isokinetic strengths and total isokinetic strength is presented in Table 2, and Table 3 compares the strength values recorded here with those presented in Dvir (2004) and Perrin (1993).

Dynamic strength, as represented by the TIS score, had a significant effect on ACB_n for three of the batch sizes ($n = 4, 5, 6$), as revealed by a Type III analysis of effects in the logistic regression (see Table 4). The ACB_n tended to decrease as the TIS increased. This tendency is illustrated in Figure 3 for the case of $n = 6$. Note that completion of a batch in one carry occurred mostly in individuals with a TIS greater than the mean (694 N·m). Parameter estimates of the TIS term in the logistic regression model for ACB_n ($n = 4, 5, 6$) indicated that with an increase in TIS of 1 N·m, participants were 0.39%, 0.62%, and 0.74% more likely to choose lower values of ACB_4 , ACB_5 ,

and ACB_6 , respectively (Karp, 2001; Stokes et al., 1995). A Type III analysis of effects revealed that TIS was a significant source of variance in ALC as well (see Table 4). Utilizing individual joint strength measurements as dependent variables in the logistic regression yielded effects similar to those observed with TIS. The correlation of strength measures at each of the joints with TIS resulted in r^2 values ranging from .8 to .9 (Table 5). No statistically significant interaction between TIS and gender was identified, suggesting that a separate analysis for men and women within each group was not necessary.

The knowledge of strength had a statistically significant effect on ACB_5 ($p = .036$) and ACB_6 ($p = .09$), as shown in Table 4. Participants with knowledge feedback of their strength utilized a significantly lower number of carries, as compared with those without knowledge feedback, when handling batches of five and six plates (according to a Tukey mean separation test; $\alpha = .1$). The mean of ACB_5 and ACB_6 were 1.41 and 1.53, respectively, for those with knowledge of their strength and 1.75 and 1.84 for those without it.

TABLE 3: Isokinetic Strength Data From This Study Compared to Data From Two Prior Studies

		Mean Strengths Reported (N·m)		
		Perrin (1993)	Dvir (2004)	Present Study
Knee extension	M	212–259	257	160
	F	118	n.a.	106
Back extension	M	246–249 ^a	178–237 ^a	283 ^b
	F	148–160 ^a	108 ^b	198 ^b
Shoulder abduction	M	85–89	51–57	57
	F	43–50	27–29	32
Shoulder extension	M	53–90	80–118	64
	F	24–60	39–54	34

Note. All values recorded at a speed of 60°/s. M = male, F = female.

^aParticipants were in a semistanding posture for the recording of values in this range of strength.

^bParticipants were in a seated posture for the recording of this strength value.

TABLE 4: The *p* Values From Type III Analysis of Effects Using Stepwise Logistic Regression

Dependent Variable	Independent Variables		
	Total Isokinetic Strength (TIS)	Knowledge of Strength	TIS-Gender Interaction Term
ACB ₄	<i>p</i> = .08*	<i>p</i> = .58	<i>p</i> = .8357
ACB ₅	<i>p</i> = .002**	<i>p</i> = .036**	<i>p</i> = .1127
ACB ₆	<i>p</i> = .0006**	<i>p</i> = .09*	<i>p</i> = .1111
ALC	<i>p</i> = .0009**	<i>p</i> = .088*	<i>p</i> = .1783

Note. The *p* values for TIS and knowledge of strength were from a regression analysis with the insignificant interaction term removed. ACB_{*n*} = average number of carries per batch of *n* plates; ALC = average load per carry.

*Significant at $\alpha = .1$; **significant at $\alpha = .05$.

Accordingly, ALC was higher for those with knowledge feedback of strength than for those without it, although the difference was not found to be statistically significant; the mean values were 3.95 versus 3.42, respectively.

When the participants were further divided according to their TIS scores – those with TIS scores in the upper half of the distribution (“stronger participants”) and those with TIS scores in the lower half of the distribution (“weaker participants”) – an interaction between knowledge feedback and strength was observed. As presented in Table 6, the differences in the average ACB_{*n*} and ACL values between the stronger and weaker participants are greater among those who did not receive knowledge feedback than among those who did.

In estimating their strength abilities relative to the general population, participants averaged a

rating of approximately 61st percentile. If the TIS score is accepted as representative of individual overall strength and the participant sample is assumed to be representative of the general population, then 21 of the 32 participants (11 in Group A and 10 in Group B) overestimated their strength with respect to the general population. The mean overestimate across the 21 participants averaged 26.95 percentile. All of the participants who underestimated their strengths were stronger individuals (i.e., TIS scores in the upper half). The mean of the actual percentile rankings for the TIS was 80th percentile for those who underestimated their strength, as compared with 34th percentile for those overestimating their strengths. Differences in batch-assorting strategy, as defined by ACB_{*n*} and ALC, were observed between those underestimating and those overestimating their strengths, and these were primarily attributed to the difference in strength between the underestimating and overestimating participants.

DISCUSSION

The present study has discovered, for the first time, a relation between dynamic (isokinetic) strength and batch-assorting strategy in completing a manual materials-handling task. More specifically, the participants with greater isokinetic strength exhibited a tendency to handle a heavier load in individual carries, thereby completing a task in fewer actions. This indicates that those who have greater abilities are more willing to carry out a task in a manner that is more efficient in terms of person-hours.

The effect of knowledge of strength on the discovered relation is also a novel finding. It was found that those who received knowledge of their strength relative to the population became more

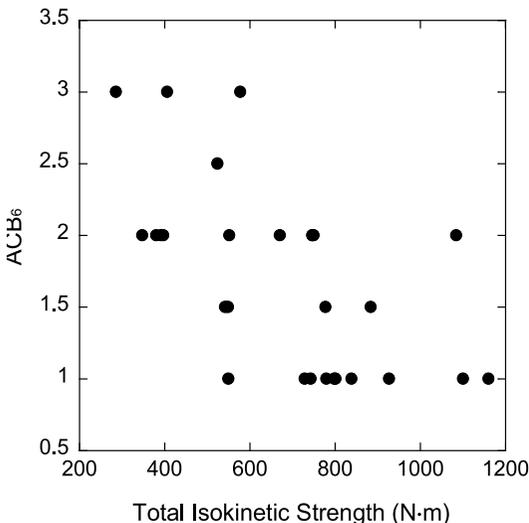


Figure 3. The average number of carries per batch of six (ACB₆) versus total isokinetic strength.

TABLE 5: The r^2 Values for Representing Correlations Between Strength Variables

	Shoulder Abduction ^a	Shoulder Extension ^a	Back Extension	Knee Extension ^a	TIS
Shoulder abduction ^a	1				
Shoulder extension ^a	.92	1			
Back extension	.53	.56	1		
Knee extension ^a	.71	.61	.61	1	
TIS	.83	.80	.83	.90	1

Note. TIS = total isokinetic strength.

^aLeft and right sides averaged.

“emboldened” in handling a heavier load per carry and completing a batch in fewer carries. Ten previous studies reviewed by Kopelman (1986) examined manual tasks in industrial settings, and in each of those studies, providing objective feedback resulted in increased production or output. Shewokis, Kennedy, and Marsh (2000) also observed that providing qualitative knowledge of results in an isokinetic shoulder rotation task allowed participants to develop internal judgment mechanisms concerning the adaptation of their movements toward a target performance. However, in each of these cases feedback concerned only past performance of the same task. What the current study was able to demonstrate was that the knowledge of competency level on one task affected the decision on the performance level of a different task.

Especially noteworthy is the finding that the knowledge of strength testing results affected the weaker and stronger groups differently. Even a simple categorization of the participants into upper and lower halves revealed this interaction

effect; had the more “polarized” data points been selected, a much more salient effect would have been observed. Receiving knowledge feedback seems to have a greater effect on weaker individuals’ batch-assorting strategy than on that of stronger individuals. Given the knowledge feedback, the participants tended to adopt a more “emboldened” strategy, and this tendency was more pronounced in the weaker participants. This response seems to reflect that the knowledge feedback evokes an impetus to “prove you wrong,” outweighing the consciousness of self-protection, particularly for those who are relatively weaker. It also suggests that the materials-handling behavior or strategy of relatively weaker individuals is more likely to be influenced by providing the knowledge of their physical capabilities.

Interestingly, it is the actual strength, not the self-perceived strength, that seemed to be the decision variable in selecting the batch-assorting strategy. The majority of participants (21 of 32) in this study believed themselves to possess greater relative strength than what was derived

TABLE 6: Mean ACB_n and ALC Values for the Two Groups of Participants, With Each Group Separated Into Stronger (Upper 50% in TIS) and Weaker (Lower 50% in TIS) Halves

Measure	Mean Values			
	Group A		Group B	
	Stronger ($n = 8$)	Weaker ($n = 8$)	Stronger ($n = 8$)	Weaker ($n = 8$)
ACB_4	1.06	1.25	1.06	1.44
ACB_5	1.38	1.44	[1.44	2.06]
ACB_6	[1.25	1.81]	[1.56	2.13]
ALC	4.29	3.60	[3.87	2.96]

Note. Group A = Participants with knowledge feedback of strength; Group B = no knowledge. TIS = total isokinetic strength; ACB_n = average number of carries per batch of n plates; ALC = average load per carry. Number pairs in brackets have significantly different values according to a Tukey mean separation test ($\alpha = .1$)

from the isokinetic testing results. The average self-perceived percentile ranking for those who overestimated their strengths was approximately the same as for those who underestimated them (61% vs. 60%, respectively), whereas the gap in average actual ranking between them was much more significant (34% vs. 80%).

Collectively, the research findings from this study have two main practical implications. One is on the utility of isokinetic strength tests in worker selection or screening. In a review of research on isokinetic testing, Newton and Waddell (1993) concluded that there is insufficient evidence to indicate that isokinetic testing is appropriate for pre-employment screening or clinical assessments. This study, however, has lent some support to the use of isokinetic strength testing in differentiating individuals' abilities in the performance of a manual materials-handling task. This is in opposition to the assertion that in order for a physical aptitude test to be valid, it must utilize the same muscle groups in the manner they would be emphasized in performing the actual work task (Dunn & Dawson, 1994). The findings from the current study indicate that tests of dynamic (isokinetic) joint strengths may be useful for identifying individuals who are likely to exert themselves at higher levels.

Another implication pertains to how job training and design should be conducted to better prevent injuries incurred during manual materials handling. A handling strategy of heavier load per carry and fewer carries per batch translates into adverse biomechanical consequences (e.g., increased joint loading and low-back stress; decreased margin of safety). Such a strategy adopted by stronger individuals seems to reflect a "risk homeostasis" model (Wilde, 1998) of coping with injury risk associated with manual acts. Physical training, including muscular strength training, has been advocated as a tool for increasing work tolerance (Genaidy, Karwowski, Guo, Hidalgo, & Garbutt, 1992). The benefit of such training, without intervention, may be offset by increased average load magnitude in handling, as evidenced in the current study. Explicit instruction or "designing-out" risky options would be a necessary intervention, particularly for repetitive handling tasks such as palletizing. In addition, providing information about people's physical capacity in an effort to influence them to adopt a more contained or cautious strategy, if not done

properly, may have the opposite effect. Although absolute performance scores may not be meaningful, relative ordinal data as provided in the current study could lead to a more risk-taking response.

The age range and general level of physical conditions for the participants in this study would lead one to believe that as a whole they are strong relative to the general population. Compared with isokinetic strength databases in the literature (Dvir, 2004; Perrin, 1993), the strength values recorded in this study were at the lower end of the ranges reported previously, except the back extension strength. Postural, demographic, and procedural factors could have contributed to the differences, however. For instance, Perrin (1993) recruited primarily an athlete population, whereas young adults were used in the current study and in what was compiled in Dvir (2004); different postures were used in these studies for testing back extension strengths, which might also explain some of the discrepancies observed.

The present study is limited in several aspects. First, the dependent measures chosen in this analysis (ACB_n and ALC) allowed simple quantification of the batch-assorting strategy during load handling. They are revealing but provide only a limited description of participants' performance. Second, the TIS was created as a single index to represent overall strength, and it seemed to summarize well the individual joint strengths, as suggested by the correlation values (r^2 between .8 and .9). However, it could be different from individual interpretations of the "overall strength capability" and from the real determining factor. The complex, multivariate nature of strength as well as the categorical nature of dependent measures may have made it more difficult to achieve statistical significance at the conventional $\alpha = .05$ level. Third, the choice of a self-preferred pace in the experiment also limits the applicability of the findings. Time constraints under a real work setting may produce different adjustments in behavior. Finally, the current study focused on the initial strategy of balancing load and pace in manual materials handling. The biomechanical and physiological consequences, including the kinematic, kinetic, and energetic responses, were not investigated. Such investigation is warranted to attain a more complete understanding of the influence of dynamic strength and related factors on materials-handling behavior and propensity for injury.

Application

The present study identified a relation between dynamic strength and batch-assorting strategy, which demonstrates the applicability of isokinetic strength tests for predicting manual materials-handling behavior in balancing productivity and injury prevention. It adds evidence supporting the use of dynamic strength testing for worker selection in general. The understanding of this relation guards the benefits of strength training and necessitates explicit instruction or “designing-out” risky options to control the tendency of stronger individuals to choose heavier loads and fewer actions. The effect of strength knowledge has implications for how to design information about mechanical capacity presented to workers to facilitate a more contained or cautious manual materials-handling strategy.

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