Effects of Accumulating Work Shifts on Performance-Based Fatigue Using Multiple Strength Measurements in Day and Night Shift Nurses and Aides

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Objective: This study aimed to examine the effects of accumulating nursing work on maximal and rapid strength characteristics in female nurses and compare these effects in day versus night shift workers.

Background: Nurses exhibit among the highest nonfatal injury rates of all occupations, which may be a consequence of long, cumulative work shift schedules. Fatigue may accumulate across multiple shifts and lead to performance impairments, which in turn may be linked to injury risks.

Method: Thirty-seven nurses and aides performed isometric strength-based performance testing of three muscle groups, including the knee extensors, knee flexors, and wrist flexors (hand grip), as well as countermovement jumps, at baseline and following exposure to three 12-hour work shifts in a four-day period. Variables included peak torque (PT) and rate of torque development (RTD) from isometric strength testing and jump height and power output.

Results: The rigorous work period resulted in significant decreases (−7.2% to −19.2%) in a large majority (8/9) of the isometric strength-based measurements. No differences were noted for the day versus night shift workers except for the RTD at 200 millisecond variable, for which the night shift had greater work-induced decreases than the day shift workers. No changes were observed for jump height or power output.

Conclusions: A compressed nursing work schedule resulted in decreases in strength-based performance abilities, being indicative of performance fatigue.

Application: Compressed work schedules involving long shifts lead to functional declines in nurse performance capacities that may pose risks for both the nurse and patient quality of care. Fatigue management plans are needed to monitor and regulate increased levels of fatigue.

Keywords: musculoskeletal injuries, occupational health, health care workers, work schedules, compressed schedules

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INTRODUCTION

The nursing profession is physically demanding, requiring many variations of physical exertion, which includes diverse types of manual handling tasks, awkward postures, and substantial time spent standing or walking (Choobineh, Rajaeefard, & Neghab, 2006; Hignett, 1996; Hui, Ng, Yeung, & Hui-Chan, 2001; Trinkoff, Lipscomb, Geiger-Brown, Storr, & Brady, 2003). Researchers have reported that nurses experience similar physical work demands, particularly for lifting, as garbage collectors and warehouse workers (Jensen, 1987) and that the frequency of lifting for nurses may be similar to that of construction workers (Klein, Jensen, & Sanderson, 1984).

The taxing physical requirements of the nursing profession is a prominent factor for the high risk of work-related musculoskeletal disorders (Choobineh et al., 2006; Trinkoff et al., 2003) that has plagued the nursing profession for decades. Nurses exhibit among the highest workplace injury rates of all occupations with a ranking of second highest for all private sector industries (Bureau of Labor Statistics, 2014). In addition to the heavy physical work demands inherent to the occupation, rigorous work schedules are commonly performed. Such schedules include long shifts, off-shifts, overtime, and compressed schedules (Geiger-Brown & Lipscomb, 2010; Hopcia, Dennerlein, Hashimoto, Orechia, & Sorensen, 2012). The physical burdens of nursing job duties coupled with long, compressed work schedules may contribute to physical performance declines across a nursing work period and be directly linked to the high injury rates.

In particular, consecutive shifts leading to cumulative work is a mostly untapped area that may provide valuable information for addressing

nurse's health needs. Interestingly, in regards to nurse's health factors, research attention has been given to the length of the shifts and overtime patterns, but the impact of consecutive shifts has largely been overlooked as a possible contributing factor for the multitude of nurse's health-related problems (Hopcia et al., 2012). In non-nursing occupations, previous research clearly shows an increased relative risk of injuries across successive shifts, with a 36% higher risk on the fourth shift versus the first shift in a series of four successive work shifts (Folkard & Tucker, 2003). This risk appears to be higher for night shifts than for the day shift schedules, although day shifts did show an increased risk across four successive shifts (Folkard & Tucker, 2003). These data highlight the potential increased risks of cumulative work patterns; however, this area of research needs to be extended into nursing occupations to elucidate the effects that such cumulative patterns may have on this profession, given the high frequency that these schedules are performed by nurses.

One approach that may be applied to glean a better understanding of the effects of successive work shifts as a risk factor for enhanced injury risks would be to examine and quantify the actual performance or functional changes that occur as a result of working multiple shifts. The quantification of fatigue has been examined and shown to be significant across a single eight-hour day shift in nurses (Hui et al., 2001). However, this research question needs to be extended toward successive shift periods and include the more commonly worked 12-hour shift durations as well as both day and night shift schedules. The assessment of fatigue may be a useful "risk management" measure (Lothschuetz Montgomery & Geiger-Brown, 2010) that may not only add clarification of these characteristics in the research realm but may be applied in practice. For example, Lothschuetz Montgomery and Geiger-Brown (2010) have suggested that "including fatigue risk measures in the dashboard would begin to address this impact of scheduling practices on nurses and patient safety" (p. 148). Given it has been demonstrated that fatigue may occur across a nursing work shift (Hui et al., 2001) and that the incidence of injury has been reported to increase at the later hours of the shift (Ryden, Molgaard, Bobbitt, & Conway, 1989), a link between fatigue and injury may exist. Such a link may find support in previous findings as Parijat and Lockhart (2008) showed that lower extremity muscle fatigue contributed to slip-induced falls, and a recent study by Thompson, Stock, Banuelas, and Akalonu (2016) showed fatigue from nursing work shifts led to impaired postural balance performance, an indirect assessment of falls likelihood. Thus, a better understanding of the magnitude and attributes of fatigue at the end of multiple shifts may help provide researchers, workers, and administrators with valuable tools and future directions targeted at minimizing injuries by managing the fatigue status of the workers.

Health care–related occupational fatigue research has commonly implemented subjective self-report assessments in the form of questionnaires (Surani, Hesselbacher, Guntupalli, Surani, & Subramanian, 2015). Although convenient to administer, such self-reported information does not provide a direct measure of actual human performance-based functionality and moreover, can be manipulated by the employee to reflect the desired outcome. Although some objective methods have been used in previous occupational studies in the context of physical performance, including heart rate recordings, RPE, fine motor performance, and postural control from nursing work (Barker & Nussbaum, 2011; Chen, Daraiseh, Davis, & Pan, 2014), force- or strength-based assessments have been largely neglected in this particular setting. Although the etiology and context of fatigue is complex, having been suggested to be multicausal, multidimensional, and even nonspecific and subjective (Barker & Nussbaum, 2011), it does appear to have a conveniently simple feature—it is relatively easily observed and manifest in high level force exertion tasks. For example, physical fatigue may be defined as "a transient decrease in the capacity to perform physical actions" (Enoka & Duchateau, 2008) or more specifically as the "reduction in the ability of muscle to produce force or power" (Sogaard, Gandevia, Todd, Petersen, & Taylor, 2006), and maximal voluntary contractions (MVCs) have been cited as the most direct assessment of physical fatigue (Vollestad, 1997; Yung, Bigelow, Hastings, & Wells, 2014). This form of strength testing offers key advantages conducive to occupational settings, which includes noninvasive protocols, minimal

preparation, short test times, and minimal participant training (Yung et al., 2014). However, the body of literature has not adequately examined maximal force-based measures of fatigue as a means to identify performance-based fatigue and as a potential assessment tool for quantifying the "fatigued" state of the worker. The need for more force-based indicators of fatigue in nursing workers is critical to advance the understanding of fatigue risk factors and prominent predisposing employee characteristics. Yung et al. (2014) reported reduced grip strength across a work week in plumbers performing physically demanding work, and Barker and Nussbaum (2011) found that simulated nursing work may have negatively impacted force variability on a lumbar extension task. However, neither of these studies examined lower body performance (the primary locomotor contributor) or rapid strength characteristics in this type of setting. Rapid strength is a special case of strength and is reported in the form of rate of torque development (RTD) (Conchola, Thiele, Palmer, Smith, & Thompson, 2015). Rapid strength has been shown to be highly relevant to human function and performance (Thompson et al., 2014; Thompson, Stock, et al., 2015) and may be sensitive to identify fatigue and indicative of the degree of loss of muscular functionality (Chiu, Fry, Schilling, Johnson, & Weiss, 2004; Conchola et al., 2015).

The use of multiple muscle groups for assessments of fatigue may help characterize the fatigue responses of the nursing worker. This would help shed light on the nature of fatigue from the type of work that nurses perform across repeated shifts. Also, muscle fatigue of the knee extensor muscles in particular has been shown to be associated with an increased risk of slips and falls (Parijat & Lockhart, 2008), which is known to be among the leading causes of injuries among nurses (Collins, Bell, & Gronqvist, 2010). However, to the best of our knowledge, this particular muscle group has never been examined in regards to the fatigue responses of rigorous nursing work. Therefore, the purpose of this investigation was to investigate the effects of a demanding, semi-cumulative nursing work shift schedule on muscle strength and rapid strength capacities of three muscle groups in female nurses and to also determine if these effects were similar for day versus night shift work schedules.

METHODS

Participants

A total of 37 female health care workers 19 to 61 years of age completed this investigation. Participant demographics included 19 day (mean ± *SD*: age = 31.2 ± 7.7 years, height = 161.5 ± 9.1 cm, mass = 75.1 ± 19.7 kg, BMI = 28.9 ± 8.0 kg/m^2) and 18 night (age = 33.5 ± 12.5 years, height = 166.0 ± 6.7 cm, mass = 72.6 ± 18.0 kg, BMI = 26.3 ± 5.9 kg/m^2) shift workers. Inclusion criteria required participants to be full-time female registered nurses (RNs), nurses' aides (CNAs), or licensed vocational nurses (LVNs) currently working 12-hour day or night shifts and had been working their current shift for a minimum of five months. Additionally, participants were required to be free of any neuromuscular diseases, sleep disorders, and musculoskeletal injuries of their dominant leg within the previous one year and could not be pregnant. This research complied with the American Psychological Association Code of Ethics and was approved by the University Institutional Review Board. Informed consent was obtained from each participant.

Experimental Procedures

These procedures have been described previously, as the data herein are part of a larger investigation (Thompson et al., 2016). Briefly, participants visited the laboratory on three separate occasions. The first visit was a familiarization session that involved the participants performing trials of all performance tests followed by the pretest session (24-96 hours later), which was scheduled within 24 hours of the first work shift and 48 to 96 hours following any previous work shift. The third and final visit was the posttest, which occurred 3 to 24 hours following the last 12-hour shift and at the same time of day as the pretest (±2 hours). The several hour delay in testing following the end of the last shift was designed to assess performances more reflective of residual or chronic fatigue rather than the effects of acute fatigue (immediately after the shift), as to provide insight into the

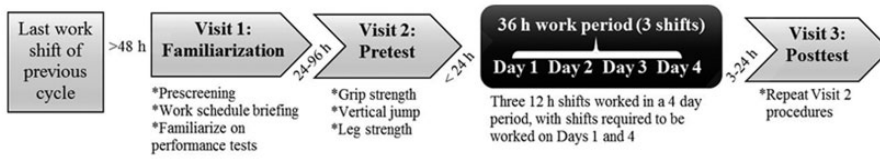

Figure 1. Schematic diagram of the study testing and experimental schedule.

fatigue effects presented in the hours following a heavy work period. This approach may allow an examination of the effects of longer lasting fatigue, which typically onsets within the first hour of physical activity task termination and may persist for over 24 hours in duration (Jones, 1996). The 4-day period between the pretest and posttest involved an experimental work period, which involved the nurse working three 12-hour work shifts in a 4-day period of which the first and fourth day were required to be a working day. This work schedule was designed to elicit a demanding multi-shift work period with 36 hours of work being performed in the context of long work shifts (12 hours) in a relatively condensed time period (96 hours)—a common work schedule feature in the nursing field. Figure 1 shows a schematic diagram of the study testing and experimental timeline. To assess the effects of work-induced fatigue, participants were instructed to refrain from any structured exercise or vigorous physical activity during the course of the study (Thompson et al., 2016).

Strength Assessments

Isometric strength assessments were performed on the knee extensors and flexors and wrist flexors (i.e., hand grip) using the right limbs. Hand grip MVCs were performed on an electronic hand grip dynamometer system (BiopacMP3X; Biopac Systems Inc, Goleta, CA), with participants performing three MVCs for the right hand. Five minutes following the hand grip MVCs, isometric knee extensions and flexions were performed on a Biodex dynamometer (Biodex System 3; Biodex Medical Systems, Shirley, NY). Before the MVCs, participants performed a warm-up protocol of 10 submaximal extension and flexion contractions. Isometric MVCs were performed for the knee extensors and flexors in random order, with three MVCs performed for each muscle action. The leg angles for the MVCs were set at 60° and 30° below the horizontal plane for the knee extensors and flexors, respectively (Conchola, Thompson, & Smith, 2013). The highest MVC was used for analysis.

Vertical Jump

Countermovement vertical jumps were performed on a force platform (AMTI, Watertown, MA). Three no-step maximal countermovement jumps were performed with 1 minute of rest between trials. Participants were required to jump without their shoes and with their hands placed on their hips to remove any influence of arm-swing on the jump performance (Palmer, Jenkins, Thompson, Smith, & Cramer, 2014). The highest vertical jump was used for analysis.

Data Analyses

The torque/force signals were sampled at either 1,926 (Biodex) or 1,000 (Hand dynamometer) Hz from the calibrated dynamometers and 1,200 Hz from the force platform and processed offline with custom written software (LabVIEW 8.5; National Instruments, Austin, TX). The signals were filtered with a fourth-order low-pass Butterworth filter with a 50 Hz cutoff frequency (de Ruiter, Kooistra, Paalman, & de Haan, 2004).

For the isometric strength variables, peak torque (PT, Nm) was determined as the highest 500-millisecond epoch during the MVC plateau region (Thompson, Ryan, & Sobolewski, 2015). RTD was quantified as the linear slope of the torque-time curves at time intervals of 0 to 50 (RTD50) and 0 to 200 (RTD200) milliseconds. These time intervals were selected to signify early (RTD50) or late (RTD200) rapid strength characteristics due to the unique physiological information provided during the distinct time

phases (Thompson et al., 2014). The onset of the signal was determined as the point when the torque signal reached a threshold of 7.5 Nm for the knee extensors and 4 Nm for the knee flexors and hand grip MVCs (Thompson, Stock, et al., 2015).

For the jump performance variables, jump height (JH, cm) was calculated using the flight time method via the formula:

$$V_{to} = \frac{gt_{flight}}{2},$$

where V_{to} is the takeoff velocity of the jumper, g is the acceleration of gravity, and t_{flight} is the time of the flight from takeoff until landing (Linthorne, 2001). The takeoff and landing onsets were determined manually. Power output (W) was quantified as the product of the ground reaction force and velocity, which was obtained via integration of the area under the acceleration curve (Dias, Dal Pupo, Gheller, Kulkamp, & Moro, 2016). Peak power was the highest value of the concentric phase of the movement (the phase between the lowest point of the center of mass and takeoff).

Statistical Analyses

Independent samples *t* tests and chi-square (χ^2) were used for demographics analyses. Eleven two-way mixed factorial (Group [day vs. night shift] × Trial [pretest vs. posttest]) analyses of variance (ANOVAs) were performed for the dependent variables. When appropriate, *t* tests were used for post hoc comparisons. Effect sizes were examined using Cohen's *d* statistics with values of 0.20, 0.50, and 0.80 corresponding to small, moderate, and large effect sizes, respectively. The statistical analyses were performed using SPSS software (Version 23.0, SPSS Inc., Chicago, IL), and an alpha level of $p \leq .05$ was used to determine statistical significance.

RESULTS

There were no differences between the day and night shift nurses for age ($p = .50$), height ($p = .10$), body mass ($p = .70$), or BMI ($p = .26$). Additionally, groups were equally matched for representation of RNs, CNAs, and LVNs between the day (RN, CNA, LVN: 13, 5, 1) and night (10, 6, 2) ($\chi^2 = 0.79$) shift nurses. Eighty-seven percent of the nurses had been working their current job and shift for at least 12 months, and the remaining 13% had worked 5 to 12 months. The mean posttest time lapse following the end of the final shift was 12.2 ± 5.4 hours.

Table 1 shows the results for the pretest versus posttest work period effects on all the variables for the day and night shift nurses. For PT, there were no Group × Trial interactions ($p = .17$, .25, .10, for knee flexors, extensors, and hand grip, respectively), but there were significant main effects for the knee flexors ($p < .01$), extensors ($p < .001$), and hand grip ($p < .001$), which were all reduced at the posttest compared to the pretest. For RTD50, there were no Group × Trial interactions ($p = .16$, .55, .96) or main effects for the knee flexors ($p = .22$), but there were significant main effects for the knee extensors ($p = .01$) and hand grip ($p = .001$), which were reduced at the posttest compared to the pretest. For RTD200, there was a significant Group × Trial interaction effect for the knee flexors ($p = .02$), with post hoc analyses revealing that no differences were observed between the pretest and posttest for the day shift nurses ($p = .84$), but the posttest was significantly lower compared to the pretest for the night shift nurses ($p < .01$) (Figure 2). No Group × Trial interactions were shown for the knee extensors ($p = .93$) or hand grip ($p = .20$) for the RTD200 variable. However, main effects were observed for these muscle actions (knee extensors, $p < .001$; hand grip, $p = .001$), with the posttest being lower compared to the pretest scores. For the jump performance variables, there were no Group × Trial interactions ($p = .58$ for JH and .48 for power) or main effects for JH ($p = .44$) and power ($p = .72$).

DISCUSSION

Declines of physical functioning were shown as a result of demanding nursing work in the context of long and cumulative work shifts. The findings provide evidence for strength-based performance declines following the demanding nursing work shift period such that all but one of the strength-related variables (8/9) showed significant declines at the posttest for the day and night shift nurses (pooled data as significant main effects). A

TABLE 1: Means (*SD*) and Effect Sizes for Day and Night Shift Workers Before (Pre) and After (Post) Working a 36-Hour Work Period

		Day Shift			Night Shift			Marginal Means (Pooled Shifts)		
Muscle Action	Variable	Pre	Post	Effect Size	Pre	Post	Effect Size	Pre	Post	Effect Size
Knee flexors	PT	84.3 (25.2)	82.1 (23.7)	0.09	80.7 (17.3)	73.9 (17.8)	0.39	82.6 (21.5)	78.1[a] (21.2)	0.21
	RTD50	321.1 (103.1)	325.2 (147.8)	0.03	309.1 (101.0)	257.9 (111.7)	0.48	315.2 (100.8)	292.4 (134.1)	0.19
	RTD200[b]	319.4 (95.1)	317.1[b] (99.1)	0.02	329.7 (74.1)	284.0[a] (76.1)	0.61	324.4 (84.5)	301.0[b] (89.0)	0.27
Knee extensors	PT	167.9 (34.7)	159.5 (32.5)	0.25	162.7 (48.2)	147.4 (46.0)	0.32	165.4 (41.1)	153.8[b] (39.3)	0.29
	RTD50	988.4 (339.7)	836.5 (457.4)	0.38	1060.6 (497.0)	817.8 (439.8)	0.52	1023.5 (419.1)	827.4[a] (442.8)	0.46
	RTD200	660.6 (202.4)	568.2 (214.2)	0.44	639.9 (202.3)	543.5 (186.6)	0.50	650.5 (199.8)	556.2[a] (198.9)	0.47
Hand grip	PF	55.0 (12.5)	52.0 (12.8)	0.24	60.8 (13.7)	53.4 (12.2)	0.57	57.8 (13.2)	52.7[a] (12.3)	0.40
	RFD50	438.6 (103.3)	381.1 (118.8)	0.52	437.1 (98.5)	378.0 (114.4)	0.56	437.9 (99.6)	379.6[a] (115.0)	0.54
	RFD200	207.5 (59.4)	194.8 (60.9)	0.21	241.8 (65.6)	214.6 (66.4)	0.41	224.2 (64.0)	204.5[a] (63.5)	0.31
Jump	JH	16.9 (5.0)	16.8 (5.1)	0.02	16.1 (5.6)	15.8 (6.1)	0.05	16.5 (5.2)	16.3 (5.6)	0.04
	Power	2,277.9 (380.4)	2,271.6 (378.6)	0.02	2,152.2 (552.3)	2,171.1 (567.1)	0.03	2,216.8 (469.5)	2,222.7 (475.5)	0.01

Note. PT = peak torque; RTD50 = rate of torque development at 50 milliseconds; RTD200 = rate of torque development at 200 milliseconds; PF = peak force; RFD = rate of force development; JH = jump height.

[a]Denotes significantly different compared to Pre ($p < .05$).

[b]Denotes a Shift × Trial interaction effect ($p = .024$).

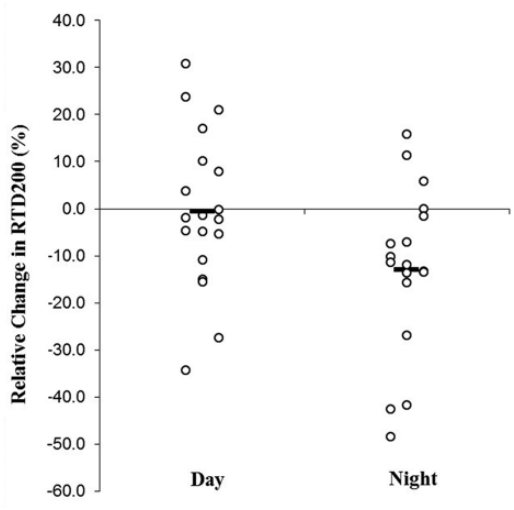

Figure 2. A scatterplot depicting individual relative change scores (%) from pre- to posttest. Data are distinguished by shift type (day and night shift) for rate of torque development at 200 milliseconds (RTD200) of the knee flexors, which showed a significant Shift × Trial interaction effect such that the night shift workers had greater work-induced declines in RTD200 compared to the day shift. The horizontal bars represent the mean change score for each shift type. RTD = rate of torque development.

close examination of the data shows that pretest-posttest relative decreases in the maximal and rapid strength capacities ranged from −5.4% to −19.2%. The largest reductions in performance were observed for the knee extensors (mean decline of all variables = −13.7%), followed by hand grip (−12.2%) and knee flexors (−6.6%) and in the early rapid strength (RTD50; mean of all muscles = −13.2%) variable with the singular greatest decline of −19.2% being the RTD50 variable for the knee extensors. This finding may have significant implications given that fatigue of the knee extensors has been shown to be linked with falls risk (Parijat & Lockhart, 2008), and given the high prevalence of low back disorders in nurses, a possible connection between lower extremity fatigue and low back injury risk may exist as a result of an imposed increased demand on the more proximal muscles during lifting tasks and/or altered lifting technique strategies that are performed in the presence of reduced lower extremity muscle strength (Li & Zhang, 2009; Trafimow, Schipplein, Novak, & Andersson, 1993; Zhang & Buhr, 2002). Moreover, these declines in strength-based performance were generally independent of shift type. This finding is similar to our previous findings (Thompson et al., 2016) on nursing work-induced reductions in reaction time and balance performance following the same nursing work period, in which we noted that the lack of disparity in performance changes between day and night shift workers could be due to more demanding workload for day shift work, even though the night shift may be more taxing from a lifestyle and circadian rhythm perspective. Perhaps the unique features inherent to each of these work shift types could each give rise to a similar fatigue response profile when assessed from a decreased performance paradigm. These results would appear to be directly indicative of fatigue, and the utility of the present strength-based measurement variables provides uniquely paramount relevance to the identification of work-induced fatigue that may be missing in previous work on occupational fatigue. This is particularly true because according to Enoka and Duchateau (2008), perhaps the most important manifestation of fatigue is a "reduction in the ability of *muscle to produce force or power* whether or not the task can be sustained" (p. 12), which is also a view supported by other authors (Sogaard et al., 2006).

The RTD200 of the knee flexors was the only strength-related variable to show significant differences between the day and night shift work schedules. Specifically, no pretest-posttest differences were found for the day workers; however, the night shift workers exhibited significant declines of 13.9%. Although we do not know the reason for this finding, we speculate that it may be a result of the potential susceptibility of this muscle group to activity-induced fatigue combined with the nature of the night shift work pattern. Previous studies have shown that the knee flexors are more sensitive to exercise-induced muscle damage in comparison to the extensors (Chen, Lin, Chen, Lin, & Nosaka, 2011; Franklin, 1993). This may be a result of the structural (e.g., longer muscle fibers and smaller size compared to the extensors) (Chen et al., 2011; Wickiewicz, Roy, Powell, & Edgerton, 1983; Wickiewicz, Roy, Powell, Perrine, & Edgerton, 1984)

and functional (e.g., higher antigravity force requirements for the extensors during many ambulatory tasks) (Jamurtas et al., 2005) attributes of the knee flexor muscle group. Chen et al. (2011) reported significantly longer recovery time for restoring the exercise-induced strength loss for the knee flexors compared to the knee extensors, thus demonstrating differential muscle-specific responses from the effects of fatigue-inducing muscular contractions. It's possible that a greater fatigue stimulus was invoked on the knee extensors due to the nature of the demanding workloads of nursing tasks, which may have exceeded a threshold for eliciting more chronic, slower recovering fatigue, but that such a level of fatigue was not met for the knee flexors, which showed no fatigue for the day workers. However, the existing residual fatigue for the night shift workers may have been a reflection of more perpetual underlying recovery incapacities, perhaps as a marker of aggregated or generalized chronic fatigue as a result of the nature of long-term night shift work patterns. In practice, this particular measure (RTD200 of the knee flexors) may be sensitive for characterizing overall functional status and recovery abilities in nursing workers, possibly capable of identifying those at higher risks of incomplete recovery—a likely factor for greater injury risk. However, future studies are warranted to determine the effectiveness of this measurement technique for identifying those workers who are at higher risk for low physical function and/or accumulated, perpetual underlying fatigue.

It is of interest that none of the jump performance variables exhibited work-induced changes despite the clear changes demonstrated for the isometric strength capacities. The countermovement jump was used as a means of assessing the gross functionality involving a complex multijoint explosive performance as this movement is often associated with functional lower body movement capabilities (Castagna et al., 2013). This movement differs in a variety of ways from the maximal isometric contractions that reflect isolated muscle strength capacities. Although the mechanisms of fatigue regarding the different contraction paradigms are beyond the scope of this study, several key distinctions may be made between the two types of muscle performance assessments in the present study. The most notable distinction is the presence of a preactivation-induced prestretch initiated by an eccentric action (countermovement), which immediately precedes the concentric muscle action phase for the jump movement, which is absent during the isometric MVCs. This dynamically loaded prestretch occurring during complex human movements, such as the countermovement jump, is characterized by the storage of elastic energy and activation or adjustment of a neural reflex response (Nicol, Avela, & Komi, 2006; Wilson & Flanagan, 2008). The physiological basis of force generation during a stretch shortening cycle movement differs mechanistically from the isolated forms of muscle action such as isometric MVCs (Nicol et al., 2006). Specifically, the storage and release of elastic energy from the prestretch movement and the activation of a neural reflex response help elicit greater force during the subsequent concentric movement (Wilson & Flanagan, 2008). Accordingly, fatigue responses of the stretch shortening cycle actions are very complex and appear more versatile than those involved in isolated muscle actions.

It is plausible that the neuromechanical attributes of the countermovement jump may have masked the presence of neuromuscular fatigue. The decline in maximal torque production observed in isolated actions may reflect changes in the central and/or peripheral functioning of the neuromuscular system, such as reduced neural drive (Halperin, Chapman, & Behm, 2015), structural impairments at the muscle level (Gissel, 2000), biochemical changes, or mental fatigue (Halperin et al., 2015). However, the principles that operate the elastic storage of energy, or afferent neuron reflex responses, may be considerably different and thus may not have been influenced by this type of activity-induced fatigue, namely, the type of fatigue that would have resulted from longer duration, submaximal activity in which a status of complete exhaustion was not attained. The practical utility of this result suggests that the use of performance tests involving heavy incorporation of the stretch shortening cycle may actually prohibit the detection of existent neuromuscular fatigue because of the force-enhancing nature of the mechanisms

of the stretch shortening cycle. These findings provide evidence demonstrating that the use of this type of movement to assess fatigue responses from demanding occupational work may not be highly sensitive as a fatigue management tool. From a fatigue assessment perspective, even though it is somewhat counterintuitive (i.e., functional movements seem desirable for assessment relevance), it appears that isolated movements in which no stretch reflex is involved (isometric actions) may be better suited as markers of fatigue status as they represent the more basic functionality of the neuromuscular physiology, unencumbered by the complexities added by dynamic movements that heavily incorporate the use of the stretch shortening cycle.

Finally, we acknowledge the potential limitations of the current study. The lack of a control group in the present investigation prevents the ability to determine potential baseline bias; however, other controls were implemented that required at least two days off work and no exercise or vigorous physical activity within the two days prior to the pretest, which helped control for differences in baseline status among nurses and increase the likelihood of them having no more than a minimal level of any residual fatigue. The present study did not assess the specific tasks performed by the nurses, which are relatively broad and may have had considerable variation between individuals and shifts; however, a key study inclusion requirement was the regular task of direct patient care, which represents a commonality of duties across nursing-related jobs. Also, the present sample included female workers working 12-hour shifts from a small sample of hospitals in Texas, which may limit the applicability of the findings to other health care–working populations. The present approach also is based on maximal effort testing procedures as a means to quantify physiological system performance outcomes, which is not a common level of intensity performed during common work tasks. Due to the multiple constructs (physical, mental, social, etc.) that may play a complex role in understanding worker performance factors, more research is warranted that encompasses multiple constructs to help build a more robust model of factors that may negatively influence employee functional capabilities.

The findings of this study offer quantifiable evidence of changes in physical functioning as a result of accumulated nursing work shifts. Most all of the explosive and maximal strength variables exhibited decreases following three 12-hour work shifts in a compressed time period. Moreover, these decreases were found for three separate muscle groups, involving both the upper and lower extremities. These decreases may represent the presence of fatigue, as identified from physiologically relevant laboratory-based fatigue measurement outcomes (isometric single joint strength testing). In practice, this may be an appealing application to help enhance efforts to identify fatigue, which may be linked to injuries and burnout in nurses working long shifts on condensed work schedules, as is typical to the health care profession. These findings help profile physical performance markers that may in turn identify performance impairment thresholds that indicate increased risks to worker and patient safety with the capability to be implemented into a "readiness to work dashboard" for employee and administrator monitoring. Finally, the present findings have likely helped identify more useful variables that are highly sensitive in the assessment of worker fatigue. The feasibility of acquiring these variables in the field is realistic given this has been effectively demonstrated by previous studies (Palmer et al., 2015; Palmer, Thiele, Conchola, Smith, & Thompson, 2016) that have performed lower body isometric strength measures in the field using a portable testing setup. Such a profiling tool may provide insight into nurses' physical capacities and/or readiness to optimally perform their duties.

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KEY POINTS

- Nursing personnel routinely work demanding schedules involving long and consecutive work shifts.

- Demanding work schedules may induce fatigue and performance decrements.
- The results of this study showed declines up to 19% in muscle function parameters following multiple long compressed work shifts in nurses and aides.
- These outcomes suggest fatigue management strategies are warranted in nursing personnel working rigorous work schedules in order to address the deleterious risks of fatigue in attempts to improve nursing personnel outcomes and the potential effects on patient care.

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