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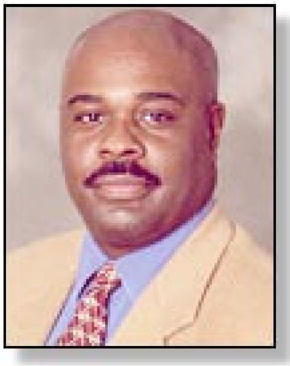

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Introduction

Repetitive strain injuries, or RSIs, represent nearly one third of all work-related injuries in the United States, costing an estimated $20 billion a year in workers' compensation and another $60 billion on accessories and equipment (Peddie, 1998). Employers and manufacturers are wary of bearing the financial responsibility for RSIs. The human cost can be even greater, affecting a person's ability to earn a livelihood or perform routine tasks of daily living. Aside from physical pain, RSIs can have a profound emotional, financial, and professional impact on an individual (Montgomery, 2003; O'Sullivan & Gallwey, 2001;).

RSIs and cumulative trauma disorders (CTDs) are a category of work-related musculoskeletal disorders (WMSDs). RSIs include carpal tunnel syndrome, tendonitis, and muscle pain caused by continually repeating small hand movements. Repetitive strain injuries affect people in hundreds of occupations and activities, such as using a computer keyboard or mouse, playing a musical instrument, or working with hand-operated equipment and tools (Quilter, 1998).

An RSI occurs when muscles perform a task or series of motions over and over again with little variation. When motions are repeated frequently (e.g., every few seconds) for prolonged periods (e.g., several hours, a work shift), fatigue and strain of the muscle and tendons can occur because there may be inadequate time for recovery (OSHA, 1999). These movements cause microscopic tears in muscles, tendons, and ligaments. The tearing leads to inflammation, and debris left by inflammation forms scar tissue that binds muscles and stiffens tendons. High repetitions over prolonged periods of time are further exacerbated when shrouded in awkward postures, high forces and insufficient rest pauses, contact stresses, continuous vibration, and cold temperatures (O'Sullivan & Gallwey, 2001; Rohmert, 1973). Regardless of the risk factor involved in leading to an RSI, providing sufficient rest is a critical factor in reducing the probability of developing an RSI.

Jobs that do not provide short pauses or breaks between motions or task cycles are often a problem because there may not be adequate time for muscles to recover from the effects of the exertion before the motion must be repeated. If there are no pauses between motions or the pauses are too short, the muscles cannot recover to the rested condition. Thus, the effects of the forces on the muscles accumulate and the muscles become fatigued and strained. The lack of adequate recovery time often occurs in jobs involving highly repetitive tasks, static loading, and motion or job tasks performed over long periods of time. Any part of the musculoskeletal system involved in moving the body is subject to injury where there is inadequate recovery time, and the recovery times needed vary by body part (OSHA, 1999).

In the light of these risk factors, many industries are being compelled to implement control measures to eliminate and reduce these types of injuries from the workplace. It should be noted that the total cost of RSIs can include personnel replacement, retraining, disruption, and lost production, which may result in a figure that is 2-3 times the compensation cost (O'Sullivan & Gallwey, 2001). Controls are typically divided into two categories: engineering and administrative. Engineering controls are preferred because of their permanency and consistency. However, they are the most difficult to implement due to cost and time spent to execute. For this reason, organizations often lean towards the use of administrative controls such as work/rest cycles and worker rotation to control worker exposure to tasks that are associated with a high injury rate. Regardless of the approach used, preventing WMSDs is a perplexing problem to solve due to a lack of knowledge of what actually causes RSIs. Although, empirical data that supports a direct link between muscle fatigue and RSIs is lacking, it is indicated that a relationship does exists between repetition, lack of rest, force, flexion and RSIs (Cantanese, 2000; Schulze, 2000; Triggs & King, 2000).

Link Between Fatigue & RSIs

This study is based on the assumption that fatigue in general can be used as an indicator of injury risk and that by minimizing fatigue the risk of injury will also be reduced. Green Green, H.J., Duhamel, S.F., Holloway, G.P., Thomas, M.M., Tupling, A.R., Rich, S.M., & **Yau, J. E.** (2004) defined fatigue as a progressive inability to generate a required or desired amount of force necessary to perform a given task. It can be brought about by a person's motivation level, a buildup of metabolites (e.g., lactic acid) in the muscle, a loss of energy supply, or a combination of these causes. During heavy dynamic work or static exercise, blood circulation cannot keep up with the muscles' demands for oxygen supply and lactate removal, which leads to lactate accumulation, lowered pH, subjective perception of fatigue, and reduced endurance (Kilbom, 1990). Fatigue is further defined as when a target force can no longer be generated and therefore resulting in a gradual fall in maximal force (Vollestad, 1997). This reduction in maximal force can be in part dependent on a person's state of fitness, muscle fiber type and composition, and the type of exercise being performed (Fitts, 1996). The onset of localized muscle fatigue is detrimental to productivity as decreased strength and loss of precise motor control can have negative effects on performance in terms of speed and quality.

Fatigue Measurement

Fatigue can be measured subjectively through the use of scales or questionnaires. Objective methods for measuring fatigue include physiological methods such as an isometric hand dynamometer. Less commonly used objective measures of fatigue include changes in performance accuracy, altered muscle and body segment coordination, and changes in posture. A research issue of interest and obvious value involves the question of which of these measures are the most valid indicators of fatigue and how they are related to one another. Although a definitive answer to this question does not exist, it has become apparent that the most valid measurements of fatigue depend on how fatigue is defined and on the reliability of the measurements. For example, if fatigue is defined as a decrease in maximal ability, as in this study, fatigue can be directly measured by taking hand strength measurements before (pretest) and after (posttest) the experiment has been performed. The difference between the pretest and posttest hand strength measurements in pounds indicate the level of fatigue present for each participant under each condition. These measurements can be accomplished using an isometric hand dynamometer that doctors and physiotherapists use for routine screening and evaluation of hand trauma or diseased hands. Hand dynamometers are also used to study muscle activity, by evaluating grip strength, relative strength of the left and right hand, muscle fatigue and endurance.

Purpose

The purpose of this study is to examine the effects of recovery time (i.e. rest periods) on fatigue and productivity of participants working in occupations where RSIs are prevalent.

This study was specifically designed to address the following research questions:

1. How does recovery time affect worker fatigue as defined by this study?
2. How does recovery time affect worker productivity?

It is important to realize that fatigue and injury are not the same. Fatigue, as defined for the purpose of this study, is a decrease in maximal ability. Work that causes fatigue appears to predispose operators to injury. In this study, fatigue is considered to be a surrogate or an indicator for potential injury. Gaining understanding about this relationship is the major reason for carrying out this study.

Method

In order to achieve the research objectives, an industrial hand task was simulated in the field. The experimental task consisted of collecting hand strength measurements and recording the number of drilled screws into a 2"x 4" pine stud. Sixteen study volunteers were randomly assigned a number of one through sixteen. The participants having numbers one through eight were assigned to the control group while participants nine through sixteen were assigned to the experimental group (i.e., eight participants to each group). Recovery time was used as the main treatment effect under the experimental condition. For the purpose of this experiment, the participants of the Control condition worked without having recovery time (breaks or stretching) versus the Experimental condition participants receiving recovery time (breaks or stretching).

The task of inserting screws was chosen because it is performed with the same hand movements used in different industries having fixed work/rest cycles. The number of screws drilled provided a means to measure productivity. Participants' productivity and muscle fatigue (i.e. hand strength) were measured and recorded under the two conditions.

The study participants were from a cross section of high RSI risk occupations (i.e. construction, assembly line, and clerical workers). The pre-test hand strength was recorded from the control and experimental groups using a JAMAR® hydraulic hand dynamometer. The JAMAR measures hand strengths between 0-200 pounds and has an accuracy of ±5% of full scale (i.e., ±10 pounds). Participants from both groups were instructed on how to use a Black and Decker 5A 3/8 inch variable speed drill in order to insert as many #6 – 1.25 inch woodscrews as possible into a wooden block. The electric drill was maneuvered and controlled by the participants applying a pistol grip to the handle with their dominant hand. The index finger was used to actuate the trigger for the drill operation. The 2 X 4 inch boards were mounted securely to a vertical wall oriented horizontally to the floor (see Figure 1.) The boards were mounted to provide an effective drill area 48 – 54 inches from the floor across a vertical wall.

The experimental group received two, two minute rest periods. A rest period was given after ten minutes of continuous drilling and the other was given after the second ten minutes of drilling. The control group received no rest periods and was required to drill for 20 minutes continuously. After 20 minutes (control) and 24 minutes (experimental including rest periods) of drilling, post-test hand strength measurements were collected. Each participant underwent testing individually with hand strength measured immediately before performing the drilling exercise according to the assigned group. Participants' number established the order participants performed the test. Participants numbering one through eight performed the test under the control condition while the remaining participants performed the test under the experimental condition. After completing the first round of testing, participants of each group (i.e. experimental and control) were reassigned to the opposite group for the second round of testing. After which, the participants returned one day later following the first round of testing and performed their reassigned group testing. Pre and Post-test hand strength measurements for the Control and Experimental conditions are presented for each subject in Table 1. The number of screws inserted by each subject is presented for each condition in Table 2.

Figure 1. Board Mounting

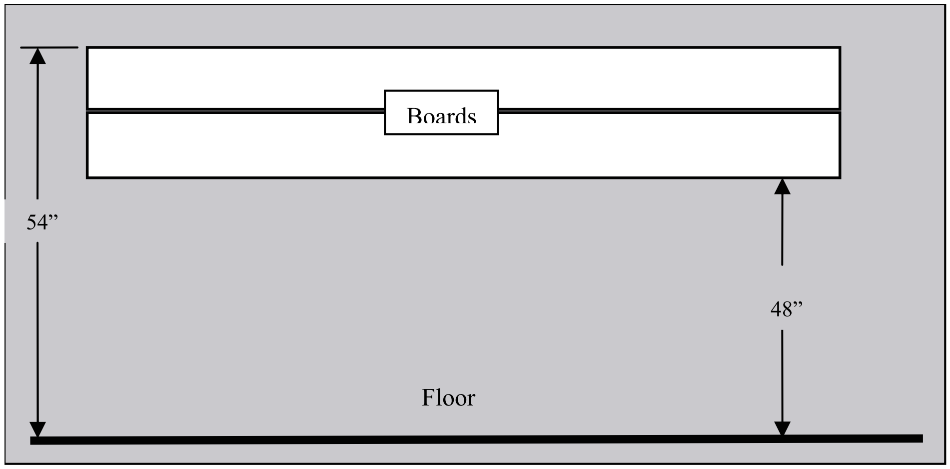

Table 1: Hand strength measurements of the Control and Experimental conditions*

Subject	Control (pre-test)	Control (post-test)	Experimental (pre-test)	Experimental (post-test)
1	58	46	66	55
2	51	42	55	50
3	125	111	123	126
4	110	99	115	108
5	133	115	138	122
6	117	109	122	115
7	72	56	78	67
8	108	100	120	112
9	75	60	80	70
10	66	50	65	59
11	77	64	85	86
12	96	87	95	90
13	78	72	80	74
14	86	80	84	88
15	77	67	81	75
16	103	80	90	87

*values presented in pounds

Table 2: Total number of screws for each participant in the Control and Experimental conditions.

Subject	Control	Experimental
1	138	142
2	114	120
3	203	196
4	210	217
5	177	186
6	184	178
7	130	138
8	154	166
9	127	138
10	115	124
11	133	140
12	206	211
13	113	122
14	133	141
15	184	198
16	199	183

Findings

SPSS Version 14 (SPSS, Inc., Chicago, USA) was used for all analysis performed in this study. The number of screws drilled under each condition was analyzed with a one-way repeated measures analysis of variance, while pre and post strength was analyzed with a two-way repeated measures analysis. The two repeated factors were Condition and Time. Paired t-test analysis were performed in order to evaluate differences among means within and between groups.

The mean numbers of screws for the control and experimental conditions are presented in Table 3. The Control condition resulted in a mean value of 157.5 screws. These values are the results of 16 participants who did not receive recovery time during hand strength measurements. The Experimental condition resulted in a mean value of 162.5 screws. These values are the result of participants who received recovery time prior to the posttest hand strength measurements. The paired t-test analysis displayed in table 4 reveals a significant difference (p=.024) in the number of screws drilled between the control and experimental conditions. This led the researchers to conclude that worker productivity was significantly influenced by recovery time. When no recovery time was given, the mean number of screws was significantly less than when recovery time was allowed. This information reveals that recovery time has a positive influence on productivity.

The results of the 2-way repeated measures ANOVA are presented in Table 5. The means for between groups (i.e., control and experiment) and within groups (i.e., pre and post hand strength within control and experimental) were evaluated for significance. The mean for the Control condition was 83.4 pounds. These values represent the Control condition Pre and Post-test hand strength measurements. Under the Experimental condition, the mean was 89.4 pounds. The paired t-test analysis displayed in table 6 reveals a significant difference (p=.000) between the control and experimental

Figure 2. Interaction Plot Between Treatment and Time Means

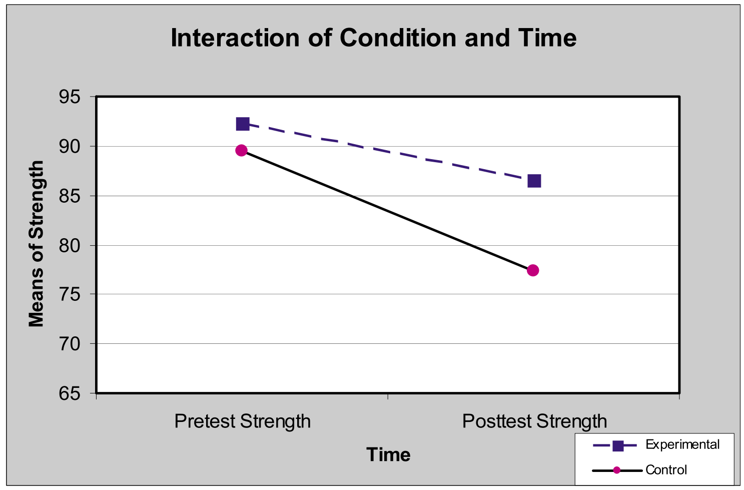

Table 3: The mean number of screws for the Control and Experimental conditions.

	Count	Mean	Std. Dev	Std. Error
Control	16	157.5	36.188	9.047
Experimental	16	162.5	33.114	8.278

Table 4: Paired T-test for number of screws between Control and Experimental condition.

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Control Experimental	-5.000	7.949	1.987	-2.516	15	.024

Table 5: The means for the main effect of Condition.

	Count	Mean	Std. Dev	Std. Error
Control	32	83.438	24.603	4.349
Experimental	32	89.406	23.993	4.241

Table 6: Paired T-test for hand strength between Control and Experimental condition

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Control Experimental	5.968	6.061	1.071	5.570	31	.000

Table 7: The means for the interaction of Condition and Time.

	Count	Mean	Std. Dev.	Std. Error
Control, Pretest	16	89.500	24.353	6.088
Control, Posttest	16	77.375	24.072	6.018
Experimental, Pretest	16	92.312	24.212	6.053
Experimental, Posttest	16	86.500	24.196	6.049

Table 8: Paired T-test of hand strength differences for Condition and Time.

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Experimental, Pretest Experimental, Posttest	5.812	5.243	1.310	4.434	15	.000
Control, Pretest Control, Posttest	12.125	4.688	1.172	10.344	15	.000

conditions. This led the researchers to conclude that recovery time was a significant factor affecting participants' hand strength between the control and experimental conditions.

The means for the interaction of condition and time are presented in Table 7 and are displayed in figure 2. The results of the paired t-test analysis displayed in table 8 reveals a significant difference (p=.000) within the control and experimental groups as a factor of time. This result indicates that hand strength decreased significantly under both conditions with a greater mean difference decrease experienced by participants of the control group where no recovery time was given.

Conclusion

The purpose of this study was to examine the effects of recovery time on participants working in occupations where RSIs are prevalent. Two questions were presented for investigation.

1. How does recovery time affect worker fatigue as defined by this study?
2. How does recovery time affect worker productivity?

Both questions were addressed by the results of the data. Recovery time had an effect on both reducing fatigue and decreasing the rate at which productivity declines over working periods. Fatigue was experienced by the participants as evidenced by the significant decrease in hand strength when pretest and posttest strength measurements are compared. Although a decrease was experienced by both groups (i.e., control and experimental), the control group experienced a greater decrease in hand strength as compared to the experimental group. The data also reveals a significant difference in the number of screws drilled between the control and experimental group participants. This difference indicates that participants receiving rest periods experienced significantly less decline in productivity than those not given rest periods.

When fatigue is minimized through recovery time, the researchers propose that repetitive strain injuries will also be reduced. By carrying out this study, it is apparent that recovery time will reduce fatigue and increase productivity. Providing workers with sufficient recovery time can be achieved by employing job rotation, where workers are routinely reassigned to other tasks. Lowering the number of repetitions per unit of time by redesigning job tasks will also provide appropriate rest periods for muscles. Coupled with the results of this study, redesigning the workspace in order to eliminate awkward work postures combined with reducing excessive grip strength requirements will further improve worker health. These and other methods can be used to reduce worker muscle fatigue, increase productivity and quality, and reduce the occurrence of RSIs and other WMSDs.

Future Research

The results of this research were limited to one measure of fatigue (i.e., hand strength measurements). Mental wellbeing and emotional state are factors that can contribute to the level of fatigue experienced by an individual. Incorporating these factors in a fatigue assessment tool will enhance the researchers' knowledge in creating a work environment that addresses more than workspace configuration. An extended study incorporating a larger participant pool, varying lengths of rest time, and work pace not controlled by the participant will prove to better enable the research to more clearly define the quantity of rest needed to overcome RSI risk factors.

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