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Comparison of Job Cognitive and Physical Demands in Different Industries for Implications on Safety Outcomes

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Abstract: With all the technological improvements and innovations to facilitate the work of field workers, construction work is still categorized as one of the most physically demanding jobs. Job nature and job requirements are often incorporated in research studies, including safety research. However, studies have neither explored the meaning of job nature and job demand, nor explored the impact of those on safety outcomes. The construction industry is also cognitively demanding, where workers have to measure materials and objects, assess work conditions, review information and identify problems, engage in decision-making, and produce a product that follows standards. Combining both cognitive and physical demands that are required to execute the work that construction projects require might be a beneficial vantage point to investigate and address accidents at work. This research aims to address the knowledge gap in our understanding of job nature by conducting a meta-analysis of both cognitive and physical demands using publicly-available data. The initial hypothesis is that jobs with a higher demand level(s), whether cognitive, physical demands, or both, have an association with a higher chance of accidents at work. To demystify this hypothesis, a comparative study between jobs in different industries was conducted. The result indicates that there is an imbalance in the level of both the cognitive demand and the physical demand between industries. Also, the result indicates a positive correlation between the demand and the negative outcomes of jobs in each industry, i.e., as the average cognitive and physical demand increase, the rate of fatalities also increases.

1 INTRODUCTION

While the construction industry has improved its safety record, it is still one of the most hazardous industries with a lot of room to improve with respect to safety. Researchers have been studying how accidents occur in order to prevent or reduce the number of accidents from happening. Generally, causes of accidents are either human failure or system failure, each of which have their own models and philosophy. With researchers discussing the rationality of system failures, such failures are also being considered as misjudgments made by a human within the system and, therefore, also constituting a human failure (Gambatese et al., 2016). In terms of the extent to which human failures are root causes of accidents, Zohar (2011) cited that, across industries, 85% of the accidents are related to human errors.

While there are many causes of human failure, the relationship between job demands and human error is the interest of this study. Job demands have been linked to many factors ranging from stress (Ng et al., 2005) and worker's health and productivity (Spurgeon et al., 1997), all the way to the overall safety of the work condition (Turner et al., 2005; Choudhry et al., 2008; Leung et al., 2012), where studies have examined job demand and job nature in terms of their impact on human error and accidents (Mitropoulos et al., 2005). Choudhry et al. (2008) reported that job conditions, if unstable, may cause problems in the implementation of safety measures.

The present study examines human error across industries through the lens of job demands and their impact on fatality rates. For the study, randomly selected trades from construction and five other selected industries are examined in terms of their physical and cognitive demands.

2 JOB DEMANDS

Each job performed in an occupation has different requirements that are needed from workers to be able to execute that job. Job demands have been studied and examined in many fields for their potential impacts on workers. A question arises as to what are task demand and job demand. Mitropoulos et al. (2009) detailed that task demand is an indicator of the degree of difficulty of the objective to execute the task at hand while successfully controlling/avoiding hazards. Therefore, it includes both the physical demands as well as the cognitive demands of the job (Mitropoulos et al., 2009). Different jobs have different needs. Some jobs have very low physical demand but perhaps higher cognitive demands. The contrary can be possible too, where jobs might have a higher level of physical demand but a lower level of cognitive demand.

A problem exists when the industry in which the workers practice has a dynamic nature, and where that dynamic nature may cause increases in the demands required to perform the job (Scharf et al., 2001). The construction industry is the industry of interest for this study, where with all the tools and equipment used, construction is still one of the most physically demanding jobs (Abdelhamid, 1999). Construction is not only physically demanding, it is also cognitively demanding and dynamic in nature (Mitropoulos et al., 2005).

3 JOB DEMANDS AND ACCIDENTS

While there is no job that does not require some ability for the job to be performed, jobs vary in terms of the levels of demands that are needed to be performed. Studies have suggested that increasing job demands increase the possibility of human errors as well as the possibility of losing control (Mitropoulos et al., 2009). This idea started with the Fuller (2000) model of Task-Capability Interface (TCI) which explained how accidents occur in driving. The model relies on the balance between task demand and the driver's capabilities, where an imbalance between the task demand and the driver's capabilities might cause loss of control. The loss of control might result in either an accident or no accident depending on the external circumstances and the applied control. Figure 1 presents a graphical representation of this concept.

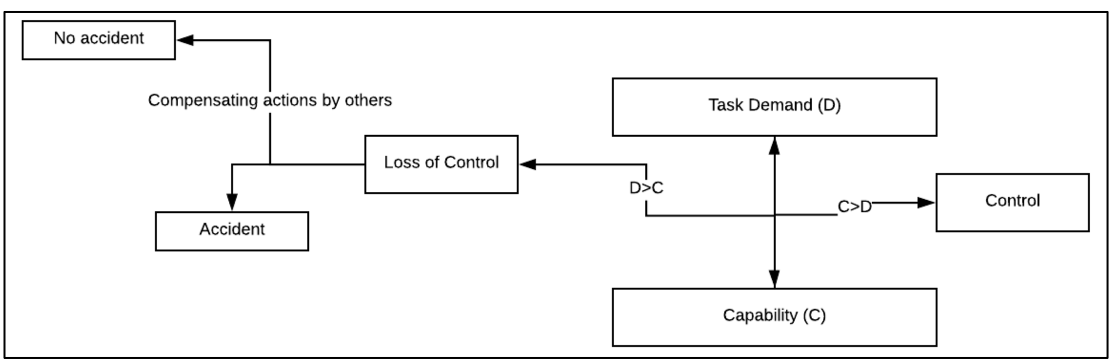

Figure 1. Task Demand and Capability Outcomes *(Fuller, 2000)*

Fuller's model suggests that an increase in the level of demand will have a negative impact on the outcome of an event if the driver capabilities are not able to accommodate the increase in demand and external measures are not applied. This model has been suggested to examine workers' cognitive demands in construction to improve safety (Mitropoulos et al., 2009). Similarly, Karasek (1979) proposed a model for the relationship between job demand and the level of control available to the worker, where higher job demand with lower control causes a strain, while having both control and demand would increase worker's activity level. Figure 2 illustrates this relationship in more detail.

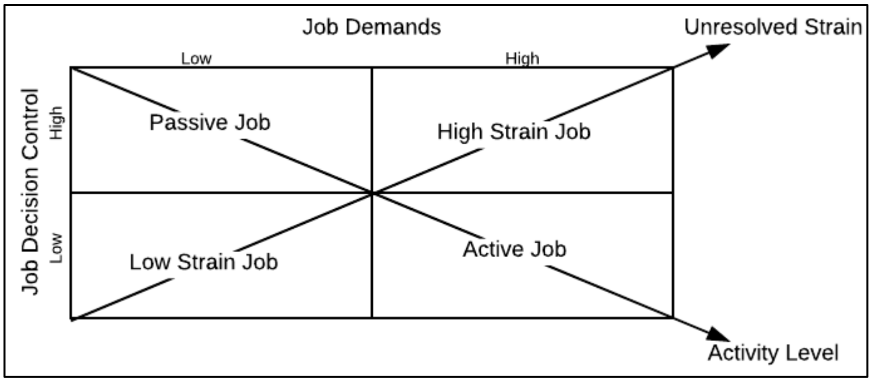

Figure 2. Job Strain Model (Karasek, 1979)

As can be seen from Figures 1 and 2, job demands have a high importance in workers' jobs. Demands are linked to both loss of control and worker burn-out. These two models have been examined in construction for their impact on safety and productivity (Snyder et al., 2008; Mitropoulos et al., 2009). However, the previous studies were narrow in scope in that they examined job demands in limited terms where either only the physical demands were considered (Abdelhamid, 1999) or there was limited consideration of cognitive demands (Mitropoulos et al., 2009). The present study aims to address this knowledge gap by considering 21 measures of cognitive demands as well as nine measures of physical demands.

4 RESEARCH METHODOLOGY

One way to examine the impact of construction cognitive and physical demands on safety is to cross-examine the industry against other industries. To perform such an evaluation, this study explores six different industries that are highly varied in their annual number of fatalities. Specifically, the study involves examining six jobs (trades) selected at random from different industries, including construction. The selected jobs are: 1) carpenters, representing the construction industry; 2) cashiers, representing the retail industry; 3) electrical power-line installers and repairers, representing the utility industry; 4) roof bolters, representing the mining industry; 5) heavy and tractor-trailer truck drivers, representing the transportation industry; and 6) farmworkers, representing the agricultural industry.

As for the measures of safety or risk to perform the comparisons, the researchers selected the following metrics:

- The annual number of fatalities. Since the number of fatalities in one industry is very different from that of another industry, similar to the number of fatalities in one trade compared to another trade in the same industry, the researchers opted to calculate a relative fatality rate. The number of fatalities for a job, cashiers for example, is divided by the number of fatalities in the entire industry, e.g., retail industry. This process is repeated for the number of fatalities from the years 2003 to 2016 for all six trades.
- Rate of fatalities for the industry per 100,000 full-time equivalent workers for the year 2013.
- The extent of exposure to hazards for each trade, which represents the frequency of exposure to the hazard in the employee's daily job, using a scale from never (0) to every day (100).

5 DATA DESCRIPTION

This study utilizes two sources of data that are available to the public. The first data source is the Occupational Information Network (O*NET) database, and the second source is the Bureau of Labor Statistics (BLS) database. The main reason for using these two public datasets is to avoid any subjectivity from the researchers or related to the research design. The development of the O*NET database was completed through a grant to the North Carolina Department of Commerce by the U.S. Department of Labor/Employment and Training Administration (USDOL/ETA). The database contains and describes about a thousand occupations that are actively engaged in the US economy.

The two measures of job demands examined are physical and cognitive. The O*NET database offers 21 cognitive demands and nine physical demands. Examples of cognitive demands included in the database are, among others, the need for deductive reasoning, memorization, and information ordering. Physical demands covered in the database include stamina, strength, and coordination. Tables 1 and 2 provide lists of the cognitive and physical demands included in the O*NET database. To better understand the extent to which each demand exists within each job (trade), O*NET provides a rating of the importance of the demand to success in the job (trade), based on a scale from 0 (low importance) to 100 (high importance). A higher number indicates greater importance to the trade. Tables 1 and 2 show the levels of importance of each cognitive demand and each physical demand, respectively, for each of the six selected trades.

Table 1: Cognitive Demands and Importance per Trade

Cognitive Demand	Importance per trade (range from 0 to 100)					
	Cashier	Electrical Worker	Roof Bolter	Driver	Carpenter	Farmworker
Category Flexibility	47	53	47	50	53	50
Deductive Reasoning	47	66	50	53	56	60
Flexibility of Closure	31	50	47	44	50	50
Fluency of Ideas	25	44	31	31	50	41
Inductive Reasoning	47	63	47	50	56	53
Information Ordering	50	66	66	53	53	56
Mathematical Reasoning	47	31	25	28	41	22
Memorization	44	31	28	25	28	35
Number Facility	50	31	25	31	44	31
Oral Comprehension	66	72	50	50	66	63
Oral Expression	69	60	50	47	60	60
Originality	28	41	28	31	50	38
Perceptual Speed	38	50	44	47	47	50
Problem Sensitivity	50	75	69	63	66	66
Selective Attention	50	50	63	53	53	53
Spatial Orientation	0	41	47	69	41	38
Speed of Closure	28	38	25	35	38	41
Time Sharing	44	47	50	47	47	41
Visualization	25	50	50	50	66	41
Written Comprehension	53	50	41	47	53	47
Written Expression	44	50	28	44	44	44

Table 2: Physical Demands and Importance per Trade

Physical Demand	Importance per trade (range from 0 to 100)					
	Cashier	Electrical Worker	Roof Bolter	Driver	Carpenter	Farmworker
Dynamic Flexibility	3	10	22	10	3	3
Dynamic Strength	25	35	47	44	38	35
Explosive Strength	13	6	28	13	10	6
Extent Flexibility	28	47	72	44	63	38
Gross Body Coordination	25	41	47	44	47	50
Gross Body Equilibrium	22	53	53	41	53	28
Stamina	25	47	53	41	53	41
Static Strength	31	53	66	50	60	60
Trunk Strength	44	47	56	47	66	56

As for the safety outcome measures for each industry, data from BLS were used. The data selected for the analysis includes the number and rate of fatalities per industry, and the exposure to hazardous conditions rating included in the O*NET database. The exposure rating reflects the extent to which workers in the industry are exposed to hazardous safety conditions, and ranges from 0 (never) to 100 (every day). Table 3 shows the values recorded by BLS and ONET for each industry.

Table 3: Safety Outcome Data per Trade (Industry)

Metric	Driver (Transportation)	Carpenter (Construction)	Farmworker (Agriculture)	Electrical Worker (Utility)	Cashier (Retail)	Roof Bolter (Mining)
Average annual number of fatalities for the industry (between 2003 and 2016)	1,345	979	609	383	280	79
Relative rate of fatalities for trade	0.166	0.076	0.029	0.543	0.116	0.182
Exposure to Hazardous Conditions (0 = Never, 100 = Every day)	1	90	91	30	24	34
Fatality rate in 2013 per 100,000 full-time equivalent workers	1.9	2.6	12.4	14	9.7	23.2

As can be seen from Table 3, each industry is different in the number of fatalities that have occurred, hazard exposure values, and rate of fatalities per 100,000 full-time equivalent. These three measures (number of fatalities, hazard exposure, and rate of fatalities) are used in the examination of the cognitive and physical demand in each industry.

6 RESEARCH ANALYSIS AND RESULTS

For both cognitive and physical demands, the researchers conducted four types of analyses: 1) a total cognitive/physical demand comparison, 2) a comparison of average demand level, 3) a comparison of relative average demand level, and 4) demand-fatality correlation analyses.

Starting with total demand, for each of the trades, a summation of the importance level of each measure was calculated. Seemingly, the summation does not explain how each of the industries performs in terms of worker fatalities. The total cognitive demand for the trades ranged from 883 (for cashiers) to 1062 (for carpenters). The total physical demand for the trades ranged from 290 (for cashiers) to 611 (for roof bolters). These total scores did not provide any indication of separation among the industries, where the individual importance of the demands canceled out. Similar results were obtained by calculating the average cognitive demand and the physical demand for each industry. The results of these analyses are shown in Table 4.

The third analysis was found to yield a more understandable result. In this case, each of the 30 demands was examined across industry, taking the average, and measuring the importance of that demand for each industry relative to all of the industries. For example, the cognitive demand "category flexibility" had the following importance ratings (as shown in Table 1): 47 (cashiers), 53 (electrical workers), 47 (roof bottlers), 50 (drivers), 53 (carpenters), and 50 (farmworkers). The average of these ratings is 50. A relative demand level is then calculated for each demand by taking the difference between the actual rating for the trade and the average rating for all trades. For the "category flexibility" cognitive demand, for example, the relative demand levels are: -3.0, 3.0, -3.0, 0.0, 3.0, and 0.0. Using this method, each demand is now rated relative to the average of all the industries combined. By adding all of the relative averages for all of the 30 demands, the total cognitive and physical demand levels were obtained. Table 4 shows the total relative cognitive and physical demands.

Table 4: Cognitive and Physical Demand Ratings per Trade

Metric	Cashiers	Electrical Workers	Roof Bolters	Drivers	Carpenters	Farmworkers
Total Cognitive Demand Level	883	1059	911	948	1062	980
Total Physical Demand Level	290	539	611	598	523	481
Average Cognitive Demand Level	42	50.4	43.4	45.1	50.6	46.7
Average Physical Demand Level	24	37.7	49.3	37.1	43.7	35.2
Total Relative Cognitive Demand	-90.8	85.2	-62.8	-25.8	88.2	6.2
Total Relative Physical Demand	-124.5	-1.5	103.5	-6.5	52.5	-23.5

Based on the results shown in Table 4, it can be clearly seen how each of the industries measures up against the average of all industries with respect to their physical and cognitive demands. As shown in the table, cashiers have the lowest physical and cognitive demands, while roof bolters have the most physically demanding job and electrical workers have the most cognitively demanding job. Except for construction (carpenters), all industries contain one or two demands that have a negative average score. That is, for the specified trade, workers had a lower than average cognitive or physical demand. Construction, on the other hand, had two positive relative importance demand levels, i.e., both are higher than average.

For the second leg of the investigation, correlation analyses were conducted. In these analyses, the relative average cognitive and physical demands were matched with the fatality scores to examine how the types of demand impact the fatalities in an industry. Starting with fatality rate per 100,000 full-time equivalent workers, the relative rate of cognitive demand was found to not be correlated, while physical demand was found to be positively correlated with a correlation coefficient of 0.30. Rate of fatality of the trade relative to the industry was determined to be negatively correlated to both the relative rate of cognitive demand, and the physical demand. The correlation coefficients were -0.19 and -0.275, respectively. Exposure to hazardous conditions was positively correlated to both the relative rate of cognitive and physical demands. Finally, when cognitive and physical demands are combined, the results show positive correlation for fatality rate (correlation coefficient = 0.168) and for exposure to hazardous conditions (correlation coefficient = 0.56). The correlation analysis results are provided in Table 5.

Table 5: Correlation Matrix for Job Demands and Safety Measures

	Fatality Rate (2013)	Rate of Fatality in the Industry	Exposure to Hazardous Conditions
Cognitive Demand	-0.03	-0.190	0.25
Physical Demand	0.30	-0.275	0.66
Cognitive and Physical Demands	0.168	-0.29	0.56

7 DISCUSSION

This study aims to understand the relationship between cognitive and physical demand and their impact on the outcome of the job in terms of safety. To do so, the researchers examined the physical and cognitive demands of six different jobs (trades) from six different industries.

By examining the O*NET data for the different jobs, it was clear that each of the jobs had different cognitive and physical needs to be performed. What drew the researchers' attention is that the difference in demand does not always present itself when calculated individually. For example, looking at the total score for cognitive demand (Table 4), construction carpentry was ranked the 4th highest job out of six in terms of cognitive demands. However, examining the relative average measure showed that this job has the second highest relative total physical demand, and all of the other jobs have a lower than average physical demand.

This result shows that, examined individually, some jobs have very high needs for a few measures of the physical and cognitive demands, while other jobs have above average demands for most of the measures of physical and cognitive needs. As a result, this finding should be taken into consideration when designing a work plan to avoid overloading workers with higher than average job demands.

Returning to the Task-Capability Interface model, it can be seen that an increase in task demand has the potential to tip the balance between control and demand, thus causing loss of control which in turn leads to an accident. Due to a lack of publicly available data about workers' control in different jobs, the researchers examined only the impact of job demands on safety outcomes.

The correlation analysis between the relative total physical demand, the relative total cognitive demand, the combined cognitive and physical demand, and the fatal work injury rate (per 100,000 full-time equivalent workers) showed that physical demand and the combination of both cognitive and physical demand are positively correlated with the fatality rate. While the correlation coefficients may be viewed as relatively low, it is important to not forget the impact of control (which was not accounted for in this study) on the outcome of a situation, as shown in the TCI model.

The calculated rate of fatalities for each job relative to the industry was not found to be correlated to the cognitive demand, and had a negative correlation with the physical demand. This outcome should be closely examined by taking multiple jobs within the same industry, because the fatality rate of a certain job might not fully represent the fatality rate per that industry.

Finally, the exposure to hazardous condition measure was also examined for correlation with both physical and cognitive demands. The jobs in which the workers more frequently encounter hazards are the jobs that require more demands from the workers. This relationship should also be considered when designing a work plan for workers in jobs that have high job demand levels.

After completing the analysis, it can be seen that high demands often are associated with high rates of fatalities. While the analysis points towards this direction, it is very important to also consider external factors when analyzing this problem. These factors can include such items as training offered for the job, types of work periods (e.g., seasonal vs. all year, and full time vs. part-time), interactions with the external environment (e.g., truck drivers on the highway have more unknowns than carpenters), etc.

8 CONCLUSIONS AND RECOMMENDATIONS

This paper provides two main contributions to the body of knowledge. The first outcome of the study is that it adds evidence to the hypothesis that cognitive demands as well as physical demands have an impact on the negative outcomes of an industry, specifically safety performance. By examining six different trades from six different industries that vary in their level of demand, it was shown that higher than average demand is positively correlated with the increase in the rate of fatalities for an industry. The second contribution this study provides is that it numerically shows evidence that the construction industry has a higher than average physical demand as well as cognitive demand. Prior research has either considered limited definitions of cognitive and physical demands, or relied on subjective assessments in this vane, while the present research provides numerical evidence.

Future studies are needed to develop methods of alleviating/reducing some of that extra job demands carried by construction workers. For example, studies are needed to explore reducing physical demands by utilizing new technology or different, more efficient tools. Consideration should also be given to finding better ways to turn construction jobs into be less cognitively demanding jobs and having risks to be more apparent to the workers.

This study is limited in one main aspect. The demand level of the randomly selected trades of each of the six industries might not be representative of the whole industry. For example, a cashier's job demand might not reflect the whole retail industry. Nevertheless, the researchers believe that taking a different sample with different trades will yield similar results. The researchers are also working on expanding the scope of the study by taking all of the trades in construction and comparing them in terms of demand level and safety outcome potential.

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