Evaluation of Dust Control Technologies for Drywall Finishing Operations: Industry Implementation Trends, Worker Perceptions, Effectiveness and Usability

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ABSTRACT

Drywall finishing operations have been associated with worker exposure to dust that contains known particulate respiratory health hazards, such as silica, talc, and mica. Despite the existence of engineering, work-practice, and personal-protective-equipment (PPE) control technologies for the mitigation of this hazard, worker exposures persist in the drywall finishing industry. This research employed a macroergonomic framework to evaluate this problem and identify barriers to dust control technology adoption in the key subsystems: personnel, technological, and organizational.

In the first study, the organizational subsystem was evaluated through a telephone interview of 264 drywall finishing firm owners. This study found the most commonly used dust control technology was respiratory protection. Cost, usability, environmental factors, and productivity were barriers identified in preventing adoption of other technologies.

In the second study, of the technological subsystem, 16 participants performed simulated drywall finishing tasks with each of four methods, in a laboratory setting. Dust particles were monitored and compared among the technologies used. Participants performed usability evaluations of the

four tools. The ventilated sander produced less respirable-size class dust than did the other three tools. The block sander produced more dust than the other three tools. Usability evaluations revealed that the block sander was easiest to learn, easiest to use, and perceived to be the best overall, while the wet method and pole sander were considered to have poor usability in terms of ease of use and productivity. Usability problems associated with perceived comfort and ease of use were identified for the ventilated sander, but it was tied for "overall best" with the block sander.

The third study, of drywall finishing worker perceptions, employed the Health Belief Model to assess barriers to technology adoption, risk, susceptibility, and benefits. Results showed that workers have a high perception of the risk associated with drywall dust, but a lower perception of individual susceptibility to disease as a result of occupational exposure. Barriers to the use of dust control technologies were identified as being associated with organizational and usability factors. Most participants indicated having access only to respiratory protection, among the available dust control methods.

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Dedication

This work is dedicated to those personally impacted by the tragic events of April 16, 2007 on the Virginia Tech campus and to the fortitude evidenced by all of our academic community.

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Chapter 1. Introduction

Statement of Problem

Respiratory disease among construction workers in general, and plasterers and wall finishers in particular, is a major public health concern. Workers in these trades suffer from disproportionately high rates of respiratory disease and disability. Drywall finishing operations have been associated with worker over-exposure to dust that contains known particulate respiratory health hazards, such as silica, talc, and mica (NIOSH, 1997). Despite the existence of engineering, work-practice, and personal-protective-equipment (PPE) control technologies for the mitigation of this hazard, worker exposures persist in the construction industry (Carlton *et al.*, 2003).

There are important gaps in the existing knowledge regarding this occupational health problem. Aside from a pilot project conducted by the National Institutes for Occupational Safety and Health (NIOSH, 2000), there has been no thorough evaluation of the effectiveness of the different dust control technologies. Additionally, investigation is needed to identify the causes of substandard controls usage. Once probable causes are identified, intervention strategies can be developed and deployed in order to improve controls usage rates in drywall finishing operations. The following research was conducted to address these gaps.

Summary of Research

Three studies were conducted as distinct parts of a collective project concept that employed a macroergonomic framework to evaluate this problem. The macroergonomic approach defines a work system as one in which two or more people work together in interaction with technology within an organizational context (Kleiner, 2006). This definition identifies three key subsystems of any work system: organizational, technological, and personnel. The organizational subsystem can be further described as having internal and external influences: physical, cultural, legal and political. According to the macroergonomic approach, all subsystems should be included in system analysis, design, and improvement (Hendrick, 2001). In the drywall finishing work system, it can therefore be assumed that organizational, human, and technological factors are important considerations when considering work designs to improve worker health. Therefore, all three subsystems were evaluated for potential barriers to the control of dust in drywall finishing operations (Figure 1).

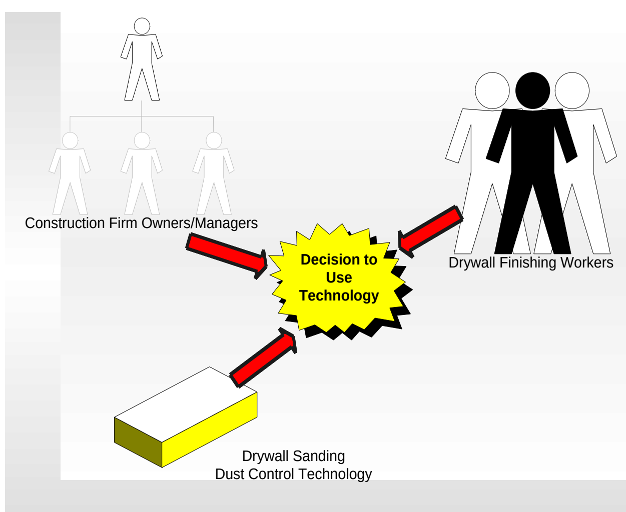

Figure 1: Subsystems of Drywall Finishing Work System

The organizational subsystem was evaluated in the first project. In this study, drywall finishing management opinion was sought via telephone survey. The technological subsystem was evaluated in the second study. Dust control effectiveness of the four main technologies in current use was compared in a laboratory study. Also in this study, a usability evaluation was performed to identify potential usability problems with the technologies. The worker subsystem was evaluated in the third study, where in-depth interviews of drywall finishing workers were conducted to elicit their attitudes toward dust control technologies and also their perceptions of the risks associated with the dust, the benefits of reducing the dust, and the barriers to using dust control technologies. Main findings of each of these studies were employed as inputs in this macroergonomic system analysis, which employed the Systems Analysis Tool (SAT: Mosard, 1982) to design and evaluate alternatives for potential system improvements.

The research employed a synthesis of techniques and models from several disparate scientific disciplines, including industrial hygiene, public health promotion, and human factors engineering. A three-fold agenda was proposed: description of industry usage trends, evaluation of technology usability and effectiveness, and evaluation of worker health behavior and attitudes as they relate to worker use of the controls technology. The construction work system, in its dynamic, informal, and decentralized nature, presents challenges to the successful completion of field research. Therefore, mixed methods were employed for data collection, consisting of both quantitative and qualitative techniques.

Study 1.

A telephone survey was administered to a target sample of 1,000 drywall-finishing contractor firms listed in the two major trade organizations in that field. This survey was constructed to measure the frequency of use of four primary and contemporary dust control technologies and respiratory protection. For each technology, firms were asked about barriers to implementation.

Study 2

In this study, problems inherent to the technology-user interface were examined. In a laboratory setting, participants performed simulated drywall finishing tasks using each of the four most common methods: plain sanding block, pole sander, wet method, and vacuum sander. Resulting dust concentrations and usability metrics were the outcomes of interest.

Study 3

Drywall finishing worker attitudes toward four technologies were explored through in-depth personal interviews. Attitudes and perceptions toward the technologies were solicited, and emergent themes were explored. The Health Belief Model, a health promotion model used to describe individual perceptions of risk, benefits, and barriers associated with a given health behavior change, served as the framework for understanding workers' readiness to adopt the control technology. Information obtained in this study can facilitate future development of interventions to improve control implementation.

The long-range goal of this research is to develop an intervention strategy that addresses those aspects of the construction work system that contribute to worker exposure to particulate respiratory hazards. These contributing factors may be any combination of work operations, tool design, health behavior, work culture, and psychosocial and organizational barriers to controls implementation. Therefore, the final chapter of this work describes a macroergonomics system analysis process employed to develop and evaluate intervention alternatives.

Literature Review

Overview

A review of the literature was undertaken and is summarized here to describe the nature of particulate respiratory hazards in general, the importance of size-selective sampling and size classes of importance in this project, the evidence of respiratory disease in construction and in drywall finishing workers, and the theoretical frameworks employed in the present studies of organizational, technological, and personnel aspects of the work system. For the organizational subsystem, the concept of risk perception, and its application to occupational safety and health, is examined. Usability is the theoretical framework employed in the study of the technological subsystem. Its application to evaluation and redesign of hand tools is reviewed. The health promotion model, Health Belief Model (HBM), provides the theoretical underpinning of the study of the personnel subsystem. Its major constructs, and the literature demonstrating their applicability to occupational health, are also reviewed.

Particulate Health Hazards: General

Drywall, or sheetrock or wallboard as it is sometimes called, consists of a non-combustible core, primarily of gypsum, with paper or vinyl covering on the sides and planar surfaces. Drywall installers fit these boards to the wall studs or ceiling joists and secure them with screws. After installation, drywall finishers prepare the surfaces for painting. The joints between the drywall sheets are taped and then pasted over with joint compound, commonly called mud, to fill the joints and any defects and screw holes in the face of the drywall board. Drywall joint compound is applied as a wet paste, which is troweled into the drywall joints. Once the compound has dried, it is firm and has the consistency and texture of chalk. The joint compound is then sanded or finished to create a smooth uniform surface. Drywall finishers typically use dry sanding techniques to create the desired surface. Dry sanding involves rubbing a coarse sand paper over the dried joint compound. Depending on the location of the work, the finishers may use pole-mounted swivel-head pad sanders and occasionally they hand sand surfaces using a sanding block. These work activities can generate substantial amounts of fine airborne particulate matter.

Particles, also known as particulates or particulate matter, are aggregate assemblages of matter in the liquid or solid states that are small enough to remain suspended in a gaseous medium (Vincent, 1999). The size range for particulates is from 10 nanometers to 100 micrometers in aerodynamic diameter. Particles with aerodynamic diameters greater than 100 micrometers have not been thoroughly studied, although recent publications indicate they may have health implications in the nasopharyngeal region (Vincent, 1999). Aerodynamic diameter, the diameter of a sphere of unit density and equivalent mass to the particle in question, is an important determinant in the regional deposition of particles in the human respiratory tract.

Particles are divided into three size classes, based on their depositional trends: inhalable, thoracic, and respirable. Inhalable particulate matter is the fraction of particles, defined in terms of a probability as a function of particle aerodynamic diameter, which is aspirated through the nose and mouth during breathing. Thoracic particulate matter is that fraction of inhalable particles that, in terms of a probability function, will deposit into the regions of the respiratory tract below the larynx. Respirable particulate matter is that fraction of inhalable particles that, again defined by a probability function, will pass into the alveolar, or gas-exchange, region of the lung. In the laboratory experiment conducted here, size-selective sampling of the drywall dust generated during the sanding task was conducted. Thoracic and respirable size classes were monitored during the simulated drywall sanding task sessions and were compared across tool types used. These size classes were chosen based upon the previously described health symptoms experienced by drywall workers (NIOSH, 1997) and the regions of the respiratory tract most likely impacted by the drywall dust exposure.

The American Conference of Governmental Hygienists defines the classes according to several probability functions (ACGIH, 2005). These functions are based on collection efficiencies of air sampling devices that model aspiration efficiency of the human respiratory system. Each size class is referred to by its median cut point, or the particle size for which there is a 50% probability of capture/inspiration. For example, the thoracic class is said to have a cut point of 10 µm (Figure 2). There is a 50% chance that particles with an aerodynamic diameter of 10 µm will be inspired into the human head and reach the regions of the respiratory system below the larynx (or captured by the air sampling device that models this respiratory function). This size class of dust particles is of interest in the present research, because exposure to drywall dust has been associated with symptomology of the middle and upper airways.

$$TPM\ (d_{ae}) = IPM\ (d_{ae})\ [\ 1 - F(x)]$$

where:

F(x) = cumulative probability function of the standardized normal variable, x

$X = \ln(d_{ae}/\text{э}) / \ln(\Gamma)$

ln = natural logarithm

э = 11.64 :m

$\Gamma = 1.5$

d_{ae} = aerodynamic diameter

(median cut points listed in bold)

Particle Aerodynamic Diameter (:m)	Thoracic Particulate Mass (%)
0	100
2	94
4	89
6	80.5
8	67
10	**50**
12	35
14	23
16	15
18	9.5
20	6
25	2

Figure 2: Collection Efficiency Thoracic Fraction

The respirable class (Figure 3) has a cut point of 4.0 :m, meaning that there is a 50% chance that particles of this size will be inspired and will reach the alveolar region of the lung. This size class of dust particles is of interest in the present research because exposure to drywall dust has been implicated in the development of pneumoconioses and other lung diseases.

$$RPM(d_{ae}) = IPM(d_{ae})\ [\ 1 - F(x)]$$

where:

F(x) = cumulative probability function of the standardized normal variable, x

$X = \ln(d_{ae}/э) / \ln(\Gamma)$

ln = natural logarithm

э = 4.25 :m

$\Gamma = 1.5$

d_{ae} = aerodynamic diameter

Particle Aerodynamic Diameter (:m)	Respirable Particulate Mass (%)
0	100
1	97
2	91
3	74
4	**50**
5	30
6	17
7	9
8	5
19	1

(median cut points in bold)

Figure 3: Collection Efficiency Respirable Fraction

During inspiration, air enters the human respiratory tract via the nares (nostrils) and flows posteriorly toward the nasopharynx through nasal hairs and circuitous passages known as the turbinates. Some particles entering the respiratory tract are intercepted in this region due to electrostatic forces between the particles and hairs or due to impaction of the particles on mucous-lined surfaces due to inertial forces, or sedimentation due to gravitational force. From the nasopharynx, air moves into the tracheobronchial tree, a system of continuously branching airways of decreasing diameter. Some particles that deposit in the nasopharyngeal region exert deleterious effects on these tissues and are associated with inflammatory and malignant disease processes.

The fate of inspired particles depends upon deposition and solubility. Particle deposition is dependent on flow rate, particle diameter, particle concentration, and air flow patterns in respiratory tract. The three principal mechanisms of deposition are inertial impaction, gravitational sedimentation, and radial diffusion. Deposition of particles larger than 10 micrometers will occur in the nasopharyngeal regions via impaction. Thoracic particles, less than 10 micrometers, will reach regions beyond the larynx, and will deposit on the mucociliary elevator for removal. Respirable particles, less than 4 micrometers in diameter, will reach the alveolar regions for deposition. Fine particles, from 0.1 to 2.5 micrometers, will remain entrained in the air stream and fail to deposit in the respiratory tract. Ultrafine particles, less than 0.1 micrometers, have been demonstrated to deposit via diffusion throughout the respiratory tract (Feron et al., 2001).

Respiratory Disease in the Construction Industry

Construction work is associated with an increased prevalence of diseases of all regions of the human respiratory system. Several recent large-scale epidemiologic studies have found associations between construction work and the morbidity and mortality of respiratory disease, and are summarized here.

In a study of proportionate mortality patterns for male construction workers in North Carolina, Wang et al. (1999) employed proportionate mortality ratios (PMRs) and proportionate cancer mortality ratios (PCMRs) to compare the number of deaths among male construction workers with those of the entire state population in the period spanning 1988-1994. The data set for this study included death certificate information from 21,617 European-American, 7,483 African-American, and 454 Other-ethnicity male construction workers. The proportionate mortality ratio (PMR) compares an observed number of deaths from a specific cause to a total number of deaths in the same time period in a referent population:

$$\text{PMR} = \frac{\text{(number of deaths from specific cause in specified time period)}}{\text{(total number of deaths during specified time period)}} \times 100$$

In this study, the number of observed deaths by cause in the study population of construction workers was compared with the number of deaths expected, based on the gender, race, and cause-specific mortality experience of the entire North Carolina population by five-year age groups for the same years of study.

Among construction workers overall, elevated mortality was observed for malignant neoplasm of the buccal cavity, pharynx, and lung. Also significant was mortality related to pneumoconiosis. When examining the data by construction trade, Wang et al. (1999) found a significant cancer risk for painters, plasterers, paperhangers, and drywall workers. This group had significantly elevated PMR's for malignant neoplasm of the pharynx (PMR = 178), of the trachea and bronchus (PMR = 118), and pneumoconiosis/other respiratory disease (PMR = 152). Specifically, drywall finishers and laborers were found to have a statistically elevated risk of death from cancer of the pharynx (PMR = 133) and lung (PMR = 110), and respiratory tuberculosis (PMR = 675). Since occupational exposure to inorganic dusts, most notably crystalline silica, has been associated with increased incidence of respiratory tuberculosis, there exists a possible explanation to the link between occupational dust exposure and this last finding.

In a 2001 epidemiologic study specific to the plastering trade, PMRs and PCMRs were calculated, using United States death rate information, for all 99 causes of death listed for the 12,873 members of the Operative Plasterers' and Cement Masons' International Association who died between 1972 and 1996 (Stern *et al.*, 2001). Members of the plasterer subgroup of this trade union perform a variety of tasks, including interior and exterior plastering of drywall, cement, stucco, and stone imitation; preparation, installation, and repair of all insulation systems; and the fireproofing of steel beams and columns. Some of the potential occupational health hazards to which this group was exposed included calcite, gypsum, mica, talc, silica, fiberglass, and asbestos. Among plasterers, significant elevated mortality was observed for lung cancer and for benign neoplasm.

Workers in the construction industry were found to possess an increased risk of pharyngeal and laryngeal neoplasms in a case-control study (Maier et *al.*, 1999). It suggests that male construction workers are at an extremely high risk for head and neck cancer. The study also suggests a synergy between inorganic dust exposure and tobacco and alcohol usage patterns on the part of the workers.

Rothenbacher et al. (1997) examined chronic respiratory morbidity among construction workers in the German construction industry. The subjects were males between the ages of 40 and 64, who were examined by the occupational health service between August 1986 and December 1988. Prevalence of respiratory disorders, as determined by chest examination, spirometry, and diagnosis of respiratory disease, was assessed in the target population and compared with the prevalence of the same indicators in a population of men not employed in the construction trades. A prospective component of this study evaluated the prognostic value of these health indicators in predicting future impairment or disability. The same participants were evaluated in 1992-1994 to determine work and life status. A non-statistically significant trend was seen toward higher prevalence of respiratory health indictors in the construction-trade workers. However, the more important finding of this study was that there was a higher rate of disability and morbidity among the construction workers in the active follow-up phase of the study. These findings correlated with signs of chronic obstructive pulmonary disease (COPD) during the chest examination of the first phase of the project. Painters and plasterers were found to have a higher prevalence of these signs upon exam, although smoking behavior was a confounding element of this study.

In a study employing Standardized Mortality Ratios (SMR) to evaluate mortality risk for construction workers from various causes, it was found that these workers have a higher risk of dying from non-transport accident and from pneumoconiosis, but not from other factors (Arndt *et al.*, 2004). Pneumoconiosis, a lung disease resulting from exposure to inorganic particulates, was the greatest risk factor identified in this large epidemiologic study of 19,943 male German construction workers.

Another recent epidemiologic study demonstrates a link between occupation and chronic obstructive pulmonary disease (Hnizdo *et al.*, 2002). Since COPD is the fourth leading cause of death among persons over the age of 45 in the United States and since the contribution of occupational exposures to the risk of COPD had not been quantified, these authors evaluated data from the Third National Health and Nutrition Examination Survey, conducted in the United States from 1988 to 1994, to calculate the prevalence and prevalence odds ratios for the association between chronic obstructive pulmonary disease (COPD) and occupation. Of the 9,823 subjects aged 30-75 for whom lung function tests were valid, 7.1% were identified as having COPD. The overall analysis identified 14 industries with increased adjusted odds ratios for COPD. Odds ratios were increased for the construction trades (3.5 for never-smoked population). In the list of 14 industries, construction was ranked third, behind Utilities (27.7) and the Armed Forces (4.4). The study found that the fraction of COPD attributable to work was 19.2% overall and 31.1% among those who have never smoked tobacco products.

In a retrospective cross-sectional study of Finnish construction painters, a dose-response relationship was found between painting years and chronic bronchitis, prolonged rhinitis, and irritative eye symptoms, as compared with a carefully matched control group (Kaukiainen *et al.*, 2005). Painters with more than 30 years of experience had odds ratios (OR) of 2.2, 2.0, and 1.8, respectively, for the symptoms. Asthma, cough, and wheezing, however were common in painters regardless of tenure in occupation, when compared to the control group. ORs were 3.1, 2.5, and 2.7 for these respiratory symptoms. Chronic bronchitis was significantly more prevalent in the painter population. The painters reported exposure to considerable levels of dust, in addition to the chemicals in paints and solvents. The authors discuss that dust from "putty and filler" was a significant risk factor for these workers. Putty and filler would be chemically similar to the drywall joint compounds under study in the proposed research.

Historically, the scientific community has focused attention on construction-related diseases of the lung and small airways, as in the cases of fibrogenic and carcinogenic mineral dusts. The bulk of the work on the occupational relatedness of upper airway disease has been in the agricultural and other organic-dust exposed work populations.

However, recent attention has been directed at possible connections between construction work and disease of the upper airways. Construction work involving high exposures to mineral dusts was associated with an elevated risk of asthma in a retrospective cohort study in Finland (Sauni *et al.*, 2003). These authors suggested that irritant mineral dusts are the etiologic agents in the reactive airway symptoms and suggest further investigation to identify specific agents.

Arif et al. (2003) found an association between asthma and construction work in a review of the data from the Third National Health and Nutrition Examination Survey 1988-1994. In this study, the prevalence of work related asthma and work related wheezing in United States workers was estimated and high-risk industries were targeted for future research and intervention. The authors found a prevalence of work related asthma of 3.70% and of work related wheezing of 11.46%. There were eight industries identified as having high risk for occupational asthma and wheezing and construction work was one asthma-risk occupation targeted by these authors as requiring additional investigation.

A study of occupational exacerbation of asthma symptoms was conducted on adult asthma patients who had been enrolled in an Health Management Organization (Henneberger *et al.*, 2002). Approximately 25% of the 1,461 participants responded positively to the questionnaire statement, “Does your current work environment make your asthma worse?” Percentages with workplace exacerbation of asthma were highest for mining and construction (36%), wholesale and retail trade (33%), and public administration (33%).

In a study of how asthma symptoms impact worker ability to perform construction work, it was found that construction workers had a higher rate of job change due to work conditions, than did the control group (Sauni *et al.*, 2001). This study found that construction worker quality of work life was greatly diminished by the exacerbation of asthma symptoms by the working conditions. The main asthma-inducing work conditions identified were the presence of dust, cold air, and physical exertion. Building renovation and insulation installation were two of the work tasks that were most problematic for the asthmatic. Drywall dust was implicated as an agent of concern.

A recent prevalence analysis was performed on 20,991 adults to estimate the United States prevalence of asthma in adults by industry of employment and to identify industries with elevated risk of asthma (Bang *et al.*, 2005). The authors used National Health Interview survey data to calculate odds ratios for asthma and industry adjusted for age, sex, race, and smoking status. Among European-Americans, the ORs were significantly elevated for printing, publishing, and allied industries and health care. Among African-Americans, the ORs were elevated for furniture, lumber, and wood and entertainment industries. Other industries with elevated ORs were construction, gasoline retail, eating and drinking places, and sanitary services.

Kaukianen et al (2005) found that construction painters experience a high prevalence of symptoms of upper-airway disease and that this prevalence was significantly higher than that of other construction-related trades workers. These authors indicated that exposure to drywall compound dust may be a significant contributing factor in this trend.

Occupational Exposure to Dust in the Construction Industry

In the most exhaustive industrial hygiene assessment to date of construction worker chemical exposures, Verma et al. (2003) found that airborne particulate matter was the most prevalent hazard class. In this study of 1,265 task-based assessments, the authors found that dust affects not only the workers involved in direct exposure-causing tasks, but also those performing ancillary activities. While this study evaluated exposures in many branches of the construction industry, residential construction tasks evaluated included framing, bricklaying, excavating, foundation building, interior carpentry, insulating, dry walling, painting, and plumbing. Residential construction tasks found to be associated with high dust generation were drywall and concrete operations. The authors note that, while it was beyond the scope of their study to measure it, wood dust appeared to be a major exposure factor in residential construction activities and they suggest future exploration. The highest particulate levels were observed during abrasive blasting, concrete grinding, cutting, chipping and concrete mixing activities. High total dusts levels were also recorded during cleanup and demolition.

A study of exposure to silica dust in the United States construction industry found that "silica exposures are grossly unacceptable in the US construction industry" (Rappaport *et al.*, 2003). Personal sampling was performed for workers in the following trades: bricklayers, painters, and laborers. Mixed models were fitted to the log-transformed air levels to estimate the means and variance components of the distributions in each trade. Probabilities of over-exposure were estimated to be between 64.5 and 100% for silica and between 8.2 and 89.2% for other dust. The authors stated that engineering and administrative controls are needed to reduce worker exposures. The study also found that silica exposures were significantly reduced by wet methods of dust suppression (300% reduction in concentrations) and ventilated enclosures (600% reduction in exposure concentration). The authors concluded that urgent action is needed to address silica over-exposure in the construction industry.

Drywall Finishing Operations and Dust Exposure

The National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of worker exposure to drywall dust and potential health effects associated with drywall finishing work during renovation activities (NIOSH, 1997). In this study of 10 workers performing drywall-sanding tasks, the main constituents of drywall joint compound, worker respiratory symptoms, and dust exposure levels were evaluated.

The construction renovation task of drywall installation was the work process of interest in this NIOSH evaluation. Personal breathing zone sampling was used to characterize exposures to total and respirable particulates. Each of the 10 workers wore two sampling devices – one for respirable and one for total dust. Respirable particulates were collected using a tared 37 mm, 5-micrometer pore PVC membrane filter in a closed-face cassette, mounted in a 10 mm nylon Dorr-Oliver cyclone and attached to a Gillian personal sampling pump. Total particulates were collected using a tared 37 mm, 5-micrometer pore PVC filter mounted in a closed-face cassette. The sampling rate for respirable particulates was 1.7 liters per minute and for total was 2 liters per minute. Cassettes were positioned in the worker breathing zone. Samples were analyzed gravimetrically for total weight according to NIOSH Method 0600. Respirable dust samples were also analyzed for the presence of crystalline silica (quartz and cristobalite) using x-ray diffraction analysis, according to NIOSH Method 7500.

Joint compound constituents were identified through collection of bulk samples from six different products purchased from a retail store. The product names are not identified in the NIOSH HEE report. Bulk samples were analyzed by x-ray diffraction and polarized light microscopy. The former permits analysis of silica and the latter permits a quantitative analysis of silicates. The joint compound constituents were identified as calcite, quartz (silica), talc, mica, gypsum, clays (attapulgite and kaolinite), and perlite. Calcite (calcium carbonate) was the primary constituent and was found in all joint compound samples, regardless of product manufacturer. Other constituents varied according to product source.

Quartz (crystalline silica) has well documented effects on the human respiratory system and has been associated with silicosis, a fibrotic disease of the lung (Merchant, 1986), and malignant neoplasm of the lung. The International Agency for Research on Cancer (IARC) has classified quartz as a "group I human carcinogen": a classification indicating that sufficient evidence of causality exists in the scientific literature.

Calcite is a form of calcium carbonate ($CaCO_3$) that is found in limestone, chalk, and marble. Calcite is selected for investigation in this study based on the fact that it is the primary constituent of joint compound and because it has been implicated in airway obstruction in a recent study (Bohadana *et al.*, 1996). This study found significant across-shift declines in all parameters associated with airway obstruction in chalk powder manufacturing workers. Chalk powder (calcium carbonate, or calcite) exposure levels correlated with airway function decrement. Although the American Conference of Governmental Hygienists (ACGIH) reports in its Documentation of Threshold Limit Values (2005) that no adverse health effects have been reported in the literature for calcite, all previous studies had examined its role in the causation of pneumoconioses. While there is no evidence to link calcite to the formation of constrictive respiratory diseases such as pneumoconioses, the Bohadana *et al.* (1996) study implicates it in the etiology of obstructive disease patterns.

The term mica refers to a family of minerals of similar chemical composition and physical properties. These are potassium aluminum silicates with variable amounts of iron and magnesium. Historically, mica was used as a thermal window in stoves and oil lamps and in early electrical appliances. Mica has been associated with pneumoconiosis (Gibbs *et al.*, 1992).

The 1997 NIOSH HHE found that respiratory symptoms were common among drywall finishers and tended to improve when workers were away from the workplace. Workers were overexposed to total dust, respirable-fraction dust, and crystalline silica. Phlegm production (63%), morning or day cough (50%), and shortness of breath (50%) were the most common. Irritated eyes (38%) and stuffy nose (25%) were reported by smaller percentages of the workers, however all who reported these symptoms also reported their resolution when away from the work setting. The upper respiratory tract symptoms associated with the “stuffy nose” symptom category is similar to reversible upper respiratory tract symptoms reported by Bohadana et al. (1996) in association with excessive calcite exposures.

In the NIOSH HHE, exposure levels to total and respirable dust were determined by full-shift breathing zone sampling. Concentrations were compared to the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PEL) of 15 mg/m^3 for total dust and 5 mg/m^3 for the respirable fraction of the dust. NIOSH found that 8 of 9 total dust samples exceeded the PEL and 2 of 13 exceeded the respirable PEL. Respirable silica (quartz) was detected in 17 of the 22 samples analyzed, albeit in trace amounts. That is, the levels of silica fell between the limit of detection and limit of quantitation for all but two samples. Two samples were found to contain silica concentrations above the limit of detection and the concentrations were reported as 0.04 mg/m^3 and 0.08 mg/m^3 as quartz. These values exceeded the NIOSH recommended exposure limit (REL) of 0.05 mg/m^3. Together, the findings of the NIOSH HHE (1997) and the Bohadana study (1996) point to the need for additional research to evaluate worker exposure to drywall dust and attendant respiratory symptomatology.

Control Technologies for Drywall Dust

To control occupational health hazards, there are three categories of controls: engineering, administrative, and personal protective equipment. It is considered best practice to select controls according to the hierarchy published by the American Conference of Governmental Industrial Hygienists (2005). Engineering controls are preferred because they eliminate or reduce the hazard and do not burden the worker. Administrative controls can be considered as a second tier option, if engineering controls are infeasible. Personal protective equipment is the least preferred, because of the burden it places on the worker.

Engineering and personal protective equipment technologies exist for the control of worker exposure to dust from construction drywall finishing operations. These controls are primarily vacuum sanding, wet sanding, pole sanding, and respiratory protection. Vacuum sanding technology involves a vacuum system attached to the sanding surface. Dust is collected at the point of generation and pulled into a collection basin. Wet sanding is accomplished in one of two methods. In one method, the drywall compound is allowed to cure and then re-wetted. Re-wetting is accomplished either by misting or wiping a damp sponge or cloth over the surface. A second method involves a combination of wet sponge and sand block. In pole sanding, the sanding surface is attached to the end of a pole and the worker holds the other end while performing the operation. This reduces worker exposure to the dust by removing the worker from the point of dust generation.

Respiratory protection is a type of personal protective equipment that is worn by the worker. Particles are intercepted on the equipment's filters before entering the worker's respiratory system. There are three general types of air-purifying respiratory protective equipment, varying in levels of effectiveness and cost. The NIOSH-approved mask is a polymer fabric filtering face-piece. A second class of respiratory protection, the negative pressure mask, is a polymer mask with replaceable filtering cartridges. The third class, positive pressure respirator, is the most protective and the most expensive. It is a battery-powered unit that provides full-face coverage and replaceable filtering cartridges.

Respiratory protection is not the preferred method of controlling worker exposure to inhalation hazards, because it places an additional burden on the worker and requires medical clearance, fitting, and training. Engineering or work practice controls are preferred, for these reasons. A NIOSH Hazard Control Study (NIOSH, 2000) found that vacuum sanding systems reduce drywall dust levels by 80 to 97 percent. Also, pole-sanding systems were found to reduce worker exposure levels by removing the sanding task from the worker breathing-zone. Work practice controls, such as wet-sanding, were effective in reducing dust levels. Respiratory protective devices, if fitted and worn properly, did reduce worker exposure to dust up to 99.99%. Despite the efficacy of these technologies, implementation by residential construction firms is not widespread. A review of the literature found no studies quantifying the implementation rates of control technologies among drywall finishing construction firms.

Perception of Risk

The present investigation of the organizational subsystem explored firm owner perception of risk associated with the drywall dust, because this construct has been found to have an impact on management decision to implement safety controls (Diaz and Resnick, 2000). Additionally, in the study of worker perceptions within a Health Belief Model framework, perceptions of the risk to individual health and susceptibility to disease were explored. Here, the chosen theoretical approach to risk perception is discussed, along with its application to the study of an occupational health problem.

The field of risk perception research is multidisciplinary, arising from diverse academic disciplines, such as psychology, decision theory, economics, anthropology, geography, and sociology and, therefore, is marked by considerable variability in its theoretical and methodological approaches. Psychological studies, which initially defined the field, beginning with Starr's article on social benefits and technological risk (Starr, 1969), have addressed the cognitive and attitudinal processes through which risks are interpreted and represented at the individual level, the evolution of opinion regarding degree of risk, and the factors that influence the acceptability of particular risks (Pidgeon and Beatie, 1998).

More recent history has seen the emergence of additional perspectives on the study of risk and human perceptions of risk. A trend in socio-cultural approaches to the study of risk perception has arisen from the fields of anthropology, sociology, and geography, where they interface with the field of risk perception. This socio-cultural approach incorporates into an understanding of risk perception the context of a range of social, cultural and political factors that frame the individual or societal understanding of risk. The socio-cultural movement in risk perception research can be said to have found its genesis in the landmark report issued by the Royal Society Study Group on Risk Analysis, Perception, and Management (Pidgeon, 1992). The years following the Royal Society report have seen a proliferation of research on such topics as geographical situation, demographic characteristics, agency and power, and trust and communication as they relate to perception of risk. Most recently, integration of the psychological and the socio-cultural perspectives has facilitated a more holistic view of the subject. These different frameworks have influenced definitions and measurement of risk perception. Recent research has approached the problem from a broader perspective, incorporating elements of the psychological framework, but also of more sociological and anthropological traditions: examining the range of social factors, such as: values, gender, race, emotions, trust, and stigma in the shaping of perceptions of risk (Finucane et al, 2000).

Since the publication of the influential Pidgeon report, the field has experienced growth in new realms. First, there has been an increasing emphasis and consolidation of research from a socio-cultural perspective. Also, the wider acknowledgement that perception is inherently related to broader social factors and processes, alongside the accumulated empirical evidence from the psychological studies, have supported the view that a purely psychological individual-based analysis of public attitudes can account for only a part of the perception of risk. The traditional approach that conceptualized the lay-public as a homogeneous risk-perceiving entity is no longer supported by most researchers in the field. Current conceptualization is of a lay public composed of various, diverse sectors and sub-groups, each with a unique set of attitudes and values that are relevant to risk perception and decision making (Pidgeon and Beattie, 1998).

In summary, the socio-cultural approach to risk perception research encompasses both the more traditional psychological perspectives and the broader contextual framework of social and cultural factors that impact risk perception, such as demographic parameters, power, agency, and trust in authority. In this new tradition, research does not focus on the individual as a stand-alone entity of a homogeneous society, but rather focuses on the individual as a member of a societal sub-culture with inherent values and beliefs that impact perception of risk.

<u>Relevance to Occupational Health</u>

The most appropriate theoretical and methodological framework for the study of perception of occupational health hazard risks would be the socio-cultural tradition. The study of occupational perceptions must be performed with consideration for the various social contexts associated with the organization. The work system is a culture with values and belief structures that impact worker and manager perceptions. The personnel in that system also belong to social and cultural sub-groups of the larger population, and these influences must be taken into account. Aspects of socio-cultural theoretical framework are particularly apt in studies in an occupational context. Power distance, personal agency, trust in authority, and demographics are all key factors in how workers will respond to risk information received in the context of the work system.

Risk perception is likely important in many aspects of the occupational health field: from the study of supervisory/management decision making regarding the implementation of control strategies or compliance initiatives, to the adoption by workers of personal protective equipment, to the adoption by workers of lifestyle factors that create additive or synergistic levels of health risk. An analysis of the perception of risk on the part of workers and managers could conceivably contribute to the development of intervention strategies to improve compliance and health outcomes.

Risk perception has been examined in its association with occupational health exposures. In a study of amosite abatement worker exposure to asbestos fibers, risk perception was assessed via traditional questionnaire methods (Stewart-Taylor & Cherrie, 1998). Associations between risk perception and asbestos-fiber-minimization-behaviors were evaluated. The authors found a clear association between risk perception and adoption of safe behaviors. More qualitative methods were employed in a study of risk perception and pesticide safety behaviors (Perry *et al.*, 1999). In a study that employed socio-cultural frameworks and methodologies more fully, Hispanic adolescent farm worker perceptions of pesticide risk were explored (Salazar *et al.*, 2004). In this project, migrant farm worker youth involved in agriculture work were assessed for attitudes toward farm work, influence of bosses, and knowledge of hazards. Additionally, the researchers assessed the microenvironment, organizational environment, and social/community environment. Qualitative methods: focus groups and observation; were employed. Cultural influences on occupational health were discussed.

Since this present research was an evaluation of multiple work system facets with the intent of identifying barriers to the adoption of health-promoting behaviors, a socio-cultural approach to the perception of risk was deemed most appropriate. In order to obtain an understanding of this construct within the organizational context, the perception of the risks to health associated with drywall dust were explored from both the management and worker perspectives. Additionally, knowledge of hazards, organizational factors, and social factors were explored in the study of workers beliefs. Both qualitative and quantitative methods were employed in the research, to allow for a more comprehensive exploration of themes.

Usability

To evaluate the technological subsystem and its impact on the decision to use dust controls, a usability evaluation of the available technology types was performed. Usability is the degree to which the design of a device or system may be used effectively and efficiently by a human (Charlton, 2002). Usability is the sub-field of human factors engineering that evaluates a technology to assess the degree to which the design may be used effectively and efficiently by a human (Charlton, 2002). Usability is defined as a composite of several attributes: learnability, efficiency, memorability, error rate, and satisfaction (Hix, 1993). A summative usability evaluation was performed in order to identify any tool-related factors that might prevent adoption and regular use by end-users. Since the sanding technologies being evaluated in this study are hand tools, usability metrics previously designed to evaluate hand tools were employed. Miller (2001) published a paper entitled "Development of a Methodology and Hardware To Conduct Usability Evaluations of Hand Tools", which contained guidelines for conducting usability evaluations of hand tools. In that document, metrics recommended for evaluating hand tool usability are: ease of use, force required, comfort levels, likelihood to drop parts, and physical characteristics of the hand tools. In another study that defined relevant usability metrics for the evaluation of hand tools, Johnson (1999) described the usefulness of subjective usability evaluations of hand tools for comfort, productivity, and ease of use. In a directly relevant study of the usability of orbital sanders, a user-reaction survey evaluated the metrics hand/arm discomfort, force required, productivity, and comfort (Spielholtz, 2001). The Spielhotz (2001) study also contained an instrument that had users rank-order the different sanders. Therefore, in the current research, a survey of user reactions was used to evaluate the following aspects of usability: ease of learning, ease of use, perceived productivity and comfort.

Health Behavior

The field of health promotion, a sub-discipline of public health, is concerned with patterns of volitional behaviors that impact overall health. Overriding goals of health promotion include the primary and secondary prevention of disease and health-compromising conditions. A central concern of health promotion is health behavior. In the broadest sense, health behavior refers to the actions of individuals, groups, and organizations, as well as their determinants, correlates, and consequences. This definition would encompass, in addition to improved individual health, such outcomes as social change, policy development, improved coping skills and enhanced quality of life (Parkerson *et al.,* 1993). A more individually-based working definition of health behavior was proposed by Gochman (1997) as: "personal attributes, beliefs, expectations, motives, values, perceptions, cognitive elements, personality, affective states, and overt behavior patterns that relate to health maintenance, health restoration, and to health improvement". Kasl and Cobb (1966) defined three categories of health behavior in their seminal work:

> *Preventive health behavior:*
>
> Any activity undertaken by an individual who believes himself [*sic*] to be healthy, for the purpose of preventing or detecting illness in an asymptomatic state;
>
> *Illness behavior:*

Any activity undertaken by an individual who perceives himself [*sic*] to be ill, to define the state of health, and to discover a suitable remedy;

Sick-role behavior:

Any activity undertaken by an individual who considers himself [*sic*] to be ill, for the purpose of getting well. It includes receiving treatment from medical providers, generally involves a whole range of dependent behaviors, and leads to some degree of exemption from one's usual responsibilities (Kasl, 1966).

Following the Kasl and Cobb (1997) definition structure, the present research evaluated drywall worker preventive health behavior: the use or non-use of technology to reduce exposure to potentially harmful dust.   According to Gochman's (2000) definition, the proposed work will evaluate those attributes that contribute to health maintenance behaviors.

Several theoretical frameworks have been developed to describe the diverse behavioral processes related to volitional health behavior: the decision to engage in health-risk, health-compromising, or health-protective behaviors. Also important is an understanding of the various individual, familial, social and cultural factors that influence the adoption and maintenance of health-compromising or health-protective behavior.   These models have been applied to personal health behaviors, such as condom use, smoking cessation, dietary changes, and adoption of exercise regimens.   A review of the literature reveals few instances of application of health promotion models to occupational health problems.

The proposed research aims to apply a health promotion theoretical framework to evaluate the health behavior of drywall finishing workers. The findings of this analysis can be fed forward into future research endeavors aimed at the development of interventions to influence the health-protective behavior rates among these workers.

The Health Belief Model

For five decades, the Health Belief Model (HBM) has been one of the most widely used conceptual frameworks in health behavior. The HBM has been used to explain both adoption (compliance) and maintenance (adherence) of behavior change. It has been employed in various configurations of the original model developed by social psychologists in the U.S. Public Health Service in the 1950's (Hochbaum, 1958) (Rosenstock, 1960). The components that have been most robust in this model are depicted in figure 4.

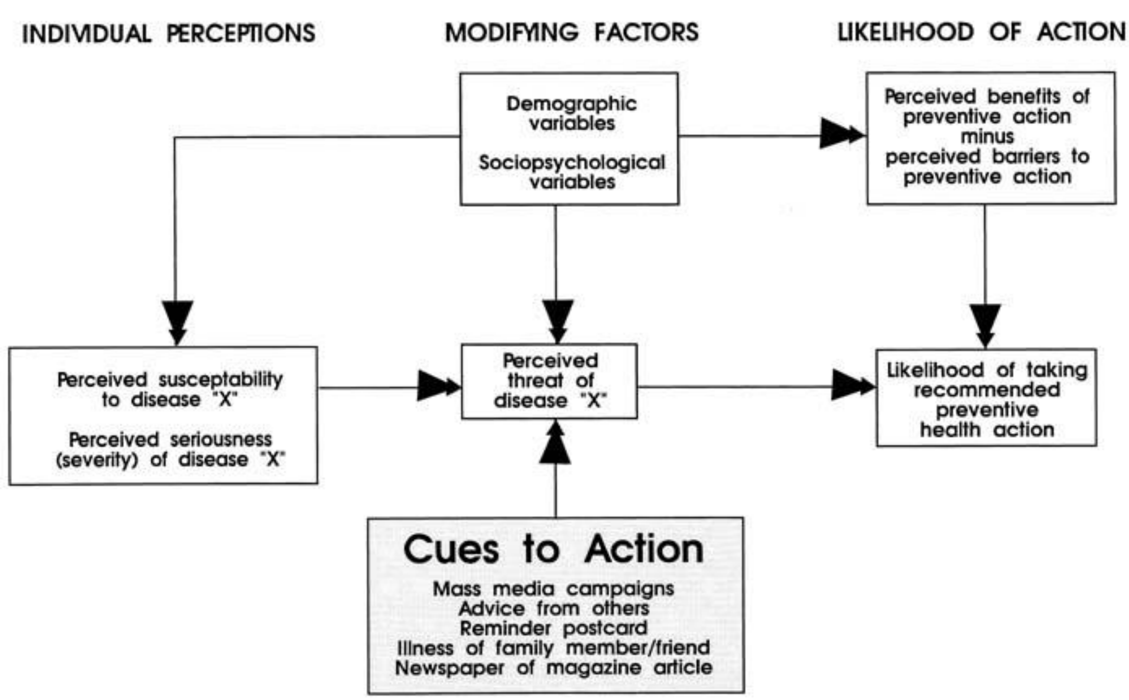

Figure 4: The Health Belief Model (adapted from Rosenstock, 1960)

Due to the complexity of the model, it has typically been tested at the level of the individual construct, rather than at the whole-model level. There is substantial empirical support for the constructs of the model and their performance in predicting health behavior. "Perceived barriers" has been found to be the strongest single predictor in the model (Janz, 1984). Therefore, the study of worker perceptions of risk associated with drywall dust aimed to identify worker perceptions of barriers to dust control technology adoption.

This conceptual framework has been employed in studies of occupational health. A study of volitional health behaviors to prevent exposure to severe acute respiratory syndrome (SARS), the Health Belief Model was used to describe perceived barriers and benefits to the use of a facemask during the performance of high-risk occupational tasks (Wong & Tang, 2005). An evaluation of Mexican workers' use of hearing protective devices found that self efficacy and perceived health status were directly influencing the decision to use the devices (Kerr *et al.*, 2002). Another study used the model to design an intervention to improve the rates of use of hearing protection devices among agricultural workers (McCullagh *et al.*, 2002). This study found that interpersonal and situation factors were primary barriers to use and were targeted in the intervention strategy.

Summary of Literature Review

This literature review reveals that workers in the construction industry suffer from disproportionate rates of respiratory disease and that particulate respiratory health hazard exposures are a significant risk factor. There is evidence that the dust generated from drywall finishing operations exceeds published occupational exposure limits for those dust constituents that have published limits, and that there are additional unregulated constituents that are suspected of having negative respiratory health impacts. Despite these findings, little study has been devoted to industry use of dust control technologies and factors leading to low usage rates.

To ensure that all facets of the work system are considered in this evaluation of barriers to the adoption of dust control technologies, the research was formulated according to a macroergonomic framework. Three studies were designed to identify barriers associated with the three key subsystems of the drywall finishing work system. The organizational subsystem was evaluated using a socio-cultural approach to risk perception analysis and technologies use. The technological subsystem was scanned through a summative usability evaluation of the technology-human interface. The personnel subsystem was explored using the Health Belief Model as a conceptual framework.

Chapter 2: Use of Dust Control Technologies within the Drywall Finishing Industry

Abstract

Objective: Quantify drywall finishing industry usage rates of dust control technology: wet methods, respiratory protection, pole sanders, ventilated sanders, and low-dust joint compound. Identify barriers to technology adoption and explore firm owner perception of risk.

Methods: A survey instrument composed of both Likert-type scaled items and open-ended items was developed and administered by telephone to the census population of the owners of member firms of trade associations: Finishing Contractors Association (FCA) and Association of the Wall and Ceiling Industries (AWCI). Of a population of 857 firms, 264 interviews were completed. Along with descriptive statistics, results were analyzed using MANOVA to examine effects of firm size and union affiliation on responses. Responses to open-ended items were analyzed using content analysis procedures.

Results: Firm owners rated the risk of dust to productivity and customer satisfaction as low-moderate. Half rated the dust as having some impact on worker health, with higher impacts indicated by owners of small firms. Among the available control technologies, respiratory protection was used most frequently. Several barriers to implementation of the more effective control technologies were identified.

Conclusions: Barriers associated with technology usability, productivity, and cost, as well as misperceptions of risk, should be addressed to improve dust control in the drywall finishing industry.

***Keywords*:** drywall, dust, construction work, dust control

Introduction

Workers in the drywall finishing industry suffer from disproportionate rates of respiratory disease (Wang, 1999). Particulate respiratory health hazard exposures are a major risk factor. There is evidence that the dust generated from drywall finishing operations exceeds published occupational exposure limits for those dust constituents that have published limits, and that there are additional unregulated constituents that are suspected of having negative impacts on respiratory health (NIOSH, 1997). Despite the existence of engineering and work-practice control technologies for the mitigation of the dust hazard, worker exposures persist in the construction industry (Carlton *et al.*, 2003).

Methods currently available to control drywall dust include vacuum sanding, wet sanding, pole sanding, respiratory protection, and a recently developed low-dust joint compound. Vacuum sanding technology involves a vacuum system with a collection hood near the sanding surface. Dust is collected at the point of generation and pulled into a collection basin. Wet sanding is accomplished using two different methods. In one method, the drywall compound is allowed to cure and then re-wetted. Re-wetting is accomplished either by misting or wiping a damp sponge or cloth over the surface. A second method involves a combination of wet sponge and sanding block. In pole sanding, the sanding surface is attached to the end of a pole and the worker holds the other end while performing the operation. This reduces worker exposure to the dust by removing the worker from the point of dust generation. While sanding poles were originally designed for the purpose of reaching distant surfaces, NIOSH (1997) recognized that they have some value in preventing worker dust exposure. Respiratory protection is a type of personal protective equipment that is worn by the worker. Particles are intercepted on the equipment's filters before entering the worker's respiratory system. Low dust joint compound, which was patented by the 3M Company in 1998, contains a dust reducing additive, such as an oil, surfactant, wax, or petroleum derivative that purportedly reduces the amount of dust resulting from sanding hardened joint compound. This compound entered the marketplace in October 2006.

Respiratory protection is not the preferred method of controlling worker exposure to inhalation hazards, because it places an additional burden on the worker and requires medical clearance, fitting, and training. Engineering or work practice controls are preferred, for these reasons. A NIOSH Hazard Control Study (NIOSH, 2000) found that vacuum sanding systems reduce drywall dust levels by 80 to 97 percent. Also, pole sanding systems were found to reduce worker exposure levels by removing the sanding task from the worker breathing-zone. Work practice controls, such as wet sanding, were effective in reducing dust levels. Respiratory protective devices, if fitted and worn properly, did reduce worker exposure to dust up to 99.99%. In terms of reducing dust in the thoracic and respirable size classes, the ventilated sander appeared superior to wet methods and pole sanders, and wet and pole methods superior to ordinary block sanding (Chapter 3).

There are important gaps in the existing knowledge base regarding this occupational health problem. A clear picture of industry usage trends for the various available technologies is needed. Also, information about drywall firm owners' and managers' perceptions of the risks associated with the dust and barriers to adoption of dust control measures, is needed in order to develop interventions to improve usage rates.

The objective of the current study was to quantify industry usage rates of the commercially available dust control technologies: vacuum sanders, wet methods, respiratory protection, pole sanders, and low-dust joint compound. Also evaluated were firm owner perceptions of risks associated with drywall dust and potential barriers to the use of controls.

Methods

Sampling Design

The study population consisted of the owners of member firms of two professional trade organizations: the Finishing Contractors Association (FCA) and the Association of the Wall and Ceiling Industries (AWCI). The FCA is the international trade association of U.S. and Canadian contractors in the drywall finishing, glass and glazing, floor covering, painting and decorating, and signs and display trades. All FCA members are signatory to collective bargaining agreements with the International Union of Painters and Allied Trades (IUPAT). AWCI represents contracting firms for acoustics systems, ceiling systems, drywall systems, exterior insulation and finishing systems, fireproofing, flooring systems, insulation, and stucco contractors, and those in allied trades. As of April 2007, the FCA had 1,400 contractor members, including 342 drywall finishing firms and the AWCI had 515 drywall finishing firm members.

Survey Instrument Design

A survey instrument (Appendix B) was designed to gather information about dust control practices and dust control technologies used in the drywall industry. Survey items regarding the negative impacts of drywall dust on productivity, customer satisfaction, and human health were included. Responses were made using a four-point Likert-type scale, with the following possible answers: great impact (1), some impact (2), not much of an impact (3), and no impact (4). The instrument also contained items about use of wet methods, respiratory protection, pole sanders, ventilated/vacuum sanders, and low-dust joint compound. These latter responses were made on a 5-point Likert-type scale with possible answers: always (1), often (2), sometimes (3), rarely (4), and never (5). Respondents answering “rarely” or “never” on these items were subsequently asked “why not?” Survey respondents were also asked to list any additional methods for controlling dust employed by their firms and to share any additional information about their experience with dust and dust control. Responses to open-ended questions were transcribed verbatim. A final set of questions addressed key demographic information of interest: number of employees, and union affiliation. All survey items were constructed by experts in survey instrument design at the Virginia Tech Center for Survey Research (VT-CSR), with content provided by the researcher.

Data Collection Procedures

The survey was conducted by phone, by interviewers at the VT-CSR. All telephone calls were made in a standardized manner, using a computer assisted telephone interviewing software system, in April, 2007. Each interviewer collecting data for the survey participated in a project-specific training session prior to participation. Interviews began with a brief summary of project objectives, a review of informed consent information, and an assurance that firm identity would never be linked to responses and that only aggregate data would be published. All calls were monitored by a phone bank supervisor to ensure data accuracy and adherence to proper interviewing protocol. Each of the 857 drywall finishing firms was contacted until reached, or to a maximum of nine attempts. These attempts were made at different times of day and on different days of the week. Firms reporting no drywall finishing work were excluded from the survey (N=217). Non-working telephone numbers, out-of-service/disconnected numbers, and answering services were excluded (N=109). The remaining pool of eligible firms was 531, with a total of 264 interviews completed, representing a response rate of 50 percent.

Analysis

Results of the scaled survey items were analyzed descriptively by percent response, means and standard deviations. Multivariate analysis of variance (MANOVA) was used to test for differences in risk perception and technology use survey responses based on firm union status (union or non-union) and firm size. Firm size was categorized into four size classes: small (1-10), medium (11-100), large (101-1,000) and very large (1,001-10,000). Subsequent univariate analyses of variance and Tukey's HSD multiple comparisons tests were performed on significant MANOVA findings, to examine individual responses. All statistical analyses were performed using JMP® 6.0.2 (SAS Institute Inc., Cary, NC).

The open-ended survey items were analyzed using content analysis procedures. Codes that were both exhaustive and mutually exclusive were established for each set of open-ended responses, by the researcher. These codes were then assigned to responses by two independent coders with education in conducting human factors research, who had been trained by the researcher on the particular coding definitions and process. Inter-rater reliability was calculated for each set of codes, using Krippendorff's alpha, with significance set at $\alpha = 0.8$ (Krippendorff, 2005). Items that did not have adequate rater agreement were not included in the frequency counts.

Results

Perception of Risk

Descriptive statistics. Of the three types of potential risks involved with dust exposure, the highest likelihood was associated with risk to worker health (Table 1).

Table 1: Firm Owner Perception of Risk

Impact	Q1: Productivity	Q2: Customer Satisfaction	Q3: Worker Health
Great	3.8	9.5	5.7
Some	34.1	31.8	44.7
Not Much	46.6	36.0	29.5
None	15.2	20.8	16.3

Percent of firm owner responses to questions regarding risks to productivity (Q1), customer satisfaction (Q2), and worker health (Q3) (scale anchors: 1 = great, 4 = none)

Mean (SD) scores for these scaled items were 2.67 (0.94) for perceived risk to worker health, 2.74 (0.77) for perceived risk to firm productivity, and 2.74 (0.96) for perceived risk to customer satisfaction. Slightly more than half of the firm owners reported a perceived threat to worker health (combining “great” and “some” responses), whereas less than 40% perceived an impact on work productivity resulting from the dust and less than

50% perceived an impact to customer satisfaction. Customer satisfaction received the largest score in both the “great impact” (9.5%) and the “no impact” (20.8%) categories. Fifteen percent of firm owners perceived no impact to productivity and 16% no impact to worker health (Figure X).

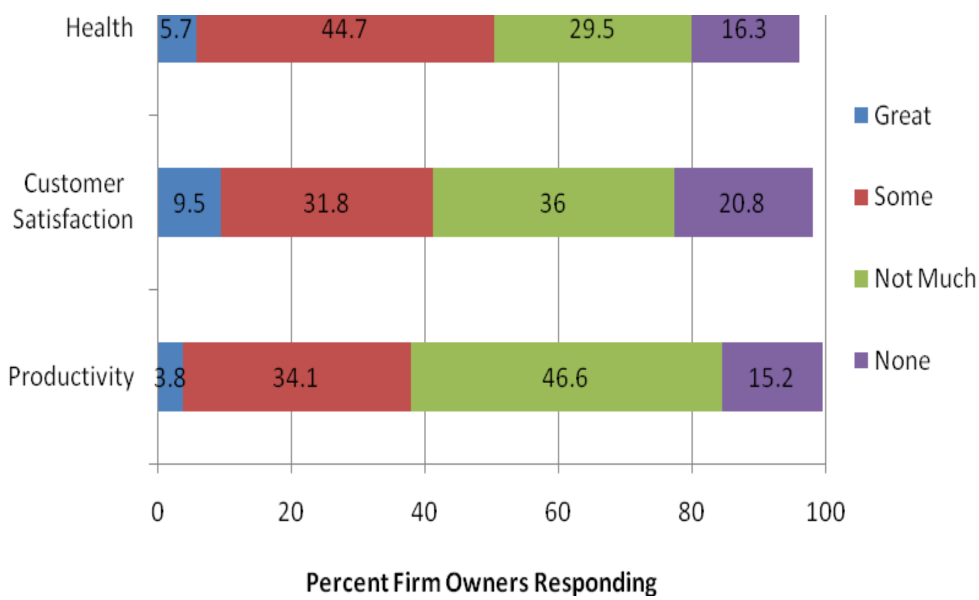

Figure 5: Firm owner perception of risk associated with drywall dust

Effects of firm size and union affiliation. Initial MANOVA of the effect of firm size and union affiliation on responses to the three risk perception questions revealed a significant effect of firm size on the perception of risk to worker health ($F(3, 260) = 3.77$, $p = 0.011$). Subsequent Tukey’s HSD all pair comparison of the means found that owners of small firms rated the risk to worker health as greater than did the owners of other size-class firms (Figure X). No other significant effects were found.

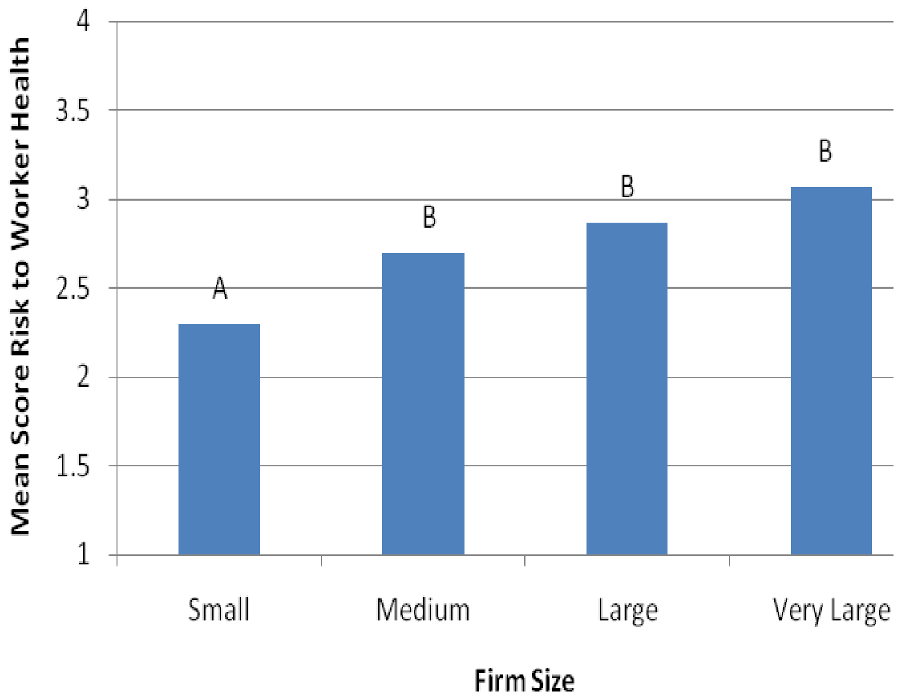

Figure 6: Firm size effects on perception of risk to worker health (Bars not sharing a common letter are significantly different)

Open-ended responses. Content analysis of responses to the open-ended questions yielded 10 comments pertaining to worker health, four pertaining to customer satisfaction, and two pertaining to productivity (Krippendorff's alpha = 0.86). Of the 10 comments pertaining to health, two indicated that there is a risk to health and eight indicated a minimal perception of the risk to worker health (Table 2). All comments pertaining to customer satisfaction (4) and productivity (2) indicated a perceived risk.

Table 2: Comments Pertaining to Perception of Risk

Response Code/Category	Comment
Health	"Makes you turn white. Necessary evil of job"
	"Have been in business for 30 years. See dust as just part of the job"
	"Wives are concerned"
	"Part of the job"
	"Safer since the asbestos has been removed from it"
	"We have never had a Worker's Compensation claim from drywall dust exposure"
	"They need to wear their respirators"
	"Up to the workers to wear protection"
	"Silica might be a problem in the dust"
	"The dust is a big problem. Glad this study is being done"
Customer Satisfaction	"Electric sanders have been our best customer satisfier"
	"Dust goes EVERYWHERE and is hard to control, even with visqueen barriers"
	"Worst part of the job. Clean up time is needed to make customer happy – dust is a pain in the butt"
	"We are trying to control it because we want our customers back"
Productivity	"Dust ruins productivity"
	"Have to have a separate crew for cleaning dust"

<u>Use of Dust Control Technologies</u>

Descriptive statistics. Among the dust control technologies, respiratory protection was the most commonly used, with a mean (SD) score of 1.35 (0.87). Pole sanders were also reportedly used at a high frequency, with a mean score of 1.96 (1.16), while firm owners reported that ventilated sanders are used sometimes, with a mean score of 2.88 (1.29). Mean scores for the wet methods was 3.67 (1.05) and for the low-dust joint compound was

3.6 (1.45), indicating the lowest usage rates among the technologies of interest. Summary frequencies for use of the dust control technologies are presented in Table 3 and Figure 7.

Table 3: Percent of firm owner responses to questions 4 through 8: use of dust control technologies

Response	Q4: Wet Methods	Q5: Respiratory Protection	Q6: Pole Sander	Q7: Ventilated Sander	Q8: Low-Dust Compound
1. Always	2.7	80.3	45.8	15.9	11.4
2. Often	7.2	11.7	28.0	24.2	9.8
3.Sometimes	38.6	3.8	16.7	33.0	28.2
4. Rarely	23.5	0.8	3.4	10.6	14.4
5. Never	27.3	3.4	5.7	15.2	29.9

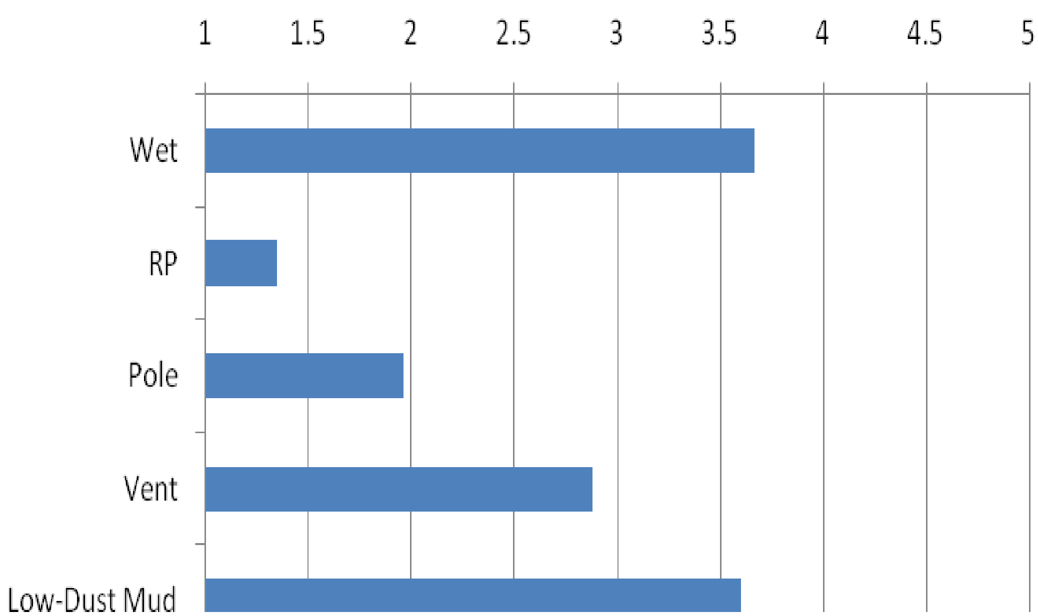

Figure 7: Mean score frequency of use per technology type (scale anchors: 1= always, 5 = never)

The technology with the greatest response in the "always" category was respiratory protection (80.3%), a score that was substantially higher than that of any of the other technologies. Combined responses for the “rarely” and “never” categories reveal that half the firm owners report very low usage rates for wet methods (50.8%) and low-dust compound (45.1%). Combined responses for the “always” and “often” ratings reveal that nearly all the firms use respiratory protection on a frequent basis (92%) and that a substantial number use pole sanders (73.8%) and ventilated sanders (40.1%). Less than ten percent of firms report using the wet methods on an “often” or “always” basis (9.9%). These findings are summarized in figure 8.

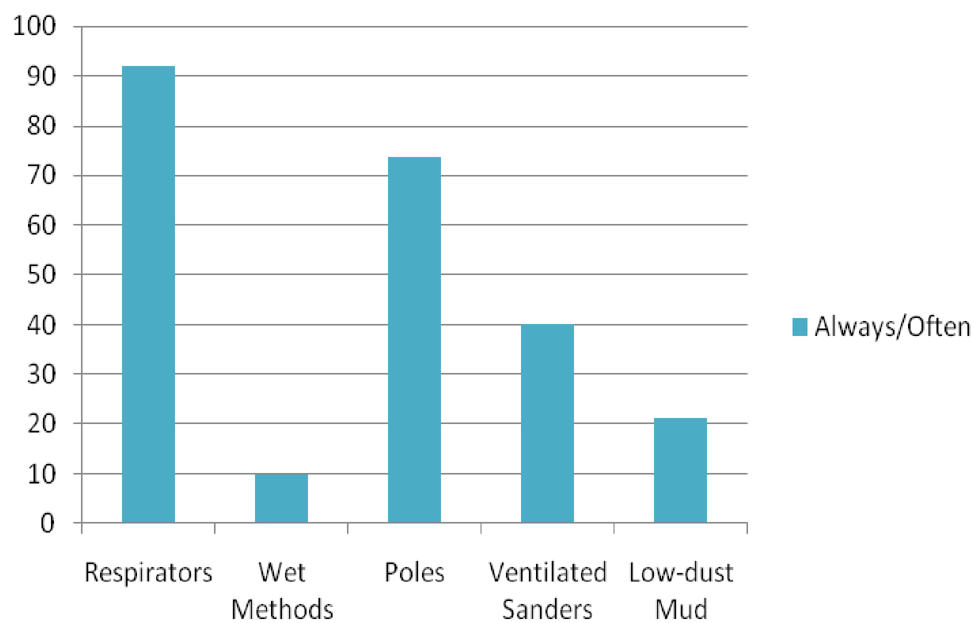

Figure 8: Percent of firms reporting “always” or “often” on use of tools

Effects of firm size and union affiliation. Initial MANOVA of the effect of firm size and union affiliation on responses to the five dust control technology use questions revealed a significant effect of union affiliation on the frequency of use of respiratory protection ($F(1, 262) = 7.46$, $p = 0.007$). Subsequent Student’s t test for means comparison found that owners of union-affiliated firms have their workers use respiratory protection significantly more frequently than do the owners of non-union-affiliated firms. No other significant effects were found.

Open-ended responses analysis. Content analysis of responses to the open-ended questions soliciting information from those firm owners answering "rarely" or "never" to are summarized in Tables 4 through 8 (Krippendorff's alpha = 0.90). Emergent themes were that quality and productivity are primary barriers associated with the wet methods. Barriers to the use of ventilated sanders are usability and environmental factors. The use of low-dust joint compound is primarily impacted by product availability. The emergent themes associated with the pole sander and ventilated sander were that firm owners were not considering their utility as worker protection tools. Many comments stated that pole sanders are not useful in reducing worker exposure to dust. Comments pertaining to the ventilated sander indicated confusion between ventilated sanding tools and general room ventilation or shop vacuum tools. There were very few comments associated with respiratory protection, since most firms use that technology on a frequent basis.

Table 4: Summary Open-ended Responses for Those Answering "Rarely" or "Never" Regarding Use of Wet Methods: Why Not Used

Response Code/Category	Frequency	Sub-categories
Quality	20	Hard to achieve desired texture/result Puts moisture back into board
Productivity	25	Takes too much time Not cost effective Easier/faster to sand dry compound vs. wet
Mess	7	Creates mess from dripping Creates mess on tools needing to be rinsed
Total responding to this item	52	

Table 5: Summary Open-ended Responses for Those Answering "Rarely" or "Never" Use of Respiratory Protection: Why Not Used

Response Code/Category	Frequency	Sub-categories
Preference	1	"Just Preference"
Risk	4	"Perceived Risk" "At worker's discretion. People who have been in the industry long don't see the need." "Equipment always available, but use not mandated. Up to the individual to use the equipment."
Total responding to this item	5	

Table 6: Summary Open-ended Responses for Those Answering "Rarely" or "Never" Regarding Use of Pole Sanders: Why Not Used

Response Code/Category	Frequency	Definition of Code/Category
Remote	8	Poles are used, but as a means of reaching remote areas to be sanded, mainly overhead
No Control	9	Poles do not provide dust control, dust is still generated, workers are still covered with dust
Total Responding to Item	17	

Table 7: Summary Open-ended Responses for Those Answering "Rarely" or "Never" Regarding Use of Ventilated or Vacuum Sanders: Why Not Used

Response Code/Category	Frequency	Sub-categories
Occupants	21	Perceived usefulness in protecting building occupants or equipment, rather than for workers. Comments such as new construction only, no occupied spaces. Comments also about usefulness in particular building types: hospitals, schools, electronic equipment spaces
Use	9	Comments about problems associated with use. Not able to achieve desired surface Workers not able to learn to use Clogs and vacuum emptying
Environmental Factors	2	No electricity on new construction Hard to use in small spaces Hard to use in large spaces – cord limitations

Productivity	13	Takes longer to do job Cost Loss due to theft
Total responding to Item	45	

Table 8: Summary Open-ended Responses for Those Answering "Rarely" or "Never" Regarding Use of Low Dust Compounds: Why Not Used

Response Code/Category	Frequency	Sub-categories
New	43	So new to market that firm hasn't tried yet Too new to be found effective Have heard of it – thinking of using it Would rather stick with familiar product Not yet available in local market Trying it now
Unfamiliar	24	Not aware of product
Cost	7	Costs more than regular mud No incentive to buy more expensive product
Quality	9	Failure to achieve desired surface Doesn't seem to really work at reducing dust Doesn't sand as easily
Total Responding to Item	83	

Results of the scaled item and content analysis of responses to the open-ended question about other methods of dust control are summarized in Tables 9 and 10. (Krippendorff's alpha = 0.83). These comments were coded into the categories "barriers", "general ventilation" and "dust clean-up". All of these comments identified methods of controlling ambient dust levels and were not methods of controlling worker exposure to dust. A summary of all findings is provided in Table 11.

Table 9: Firm Responses to the Question: "Does your firm use any <u>other methods</u> of controlling dust generation, other than those I've mentioned?"

Response	Frequency	Percent
Yes	75	28.4
No	188	71.2
Don't Know	1	0.4
Total	264	100.0

Table 10: Summary Open-ended Responses for Question 9: "Does your firm use any other methods of controlling dust generation, other than those I've mentioned?"

Response Code/Category	Frequency	Sub-categories
Barriers and Containment systems	33	Tarps Visqueen Ecomembrane Polyvinyl sheeting Barricades Zipwall systems Mask off doors Negative air pressure with HEPA filter
General, Ambient, or Dilution Ventilation	22	Open-air projects Open windows Fans Fans with HEPA filters Negative air machines
Dust Clean-up Post Sanding	4	Sweeping Sponging areas (mentioned around computer equipment) Shop vacuum
Other	4	Skill Special system: "dry towels"

Table 11: Summary of Findings

1. **Respiratory protection is used more often than other dust control methods.**

    a. More firms reported “always” using respiratory protection equipment, as compared to the other dust control technologies.

    b. More firms reported any frequency of use of respiratory protection as compared to the other methods of dust control.

2. **Barriers to the use of ventilated sanders include:**

    a. Environmental factors: no power source on new construction jobs, cord limitations on larger-area jobs, difficult to maneuver in smaller-area jobs.

    b. Usability factors: more difficult for workers to learn to use effectively and efficiently

    c. Cost: more expense equipment, productivity concerns, theft concerns

3. **Barriers to the use of low-dust joint compound include:**

    a. Cost: lack of incentive to purchase product that costs more than conventional joint compound

    b. Availability: product is not available in all markets.

4. **Barriers to the use of wet methods.**

    a. Quality: not possible to achieve desired result.

    b. Productivity: much less efficient than other methods

    c. Mess: wet compound drips and creates additional clean-up work. Water can penetrate wall board and damage it.

5. **Firm owner misconceptions serving as barriers to dust control.**

    a. A belief that dust control is aimed at preventing building occupant or equipment exposure, rather than worker exposure.

    b. Half of firm owners did not perceive a risk to worker health.

    c. A belief that dilution ventilation is adequate for dust control.

Discussion

The present work is part of a larger effort to identify barriers inherent to the drywall finishing work system that are preventing the use of available dust control technologies. In this larger project, each subsystem of the work system is evaluated to identify key causal factors. In the present study, the organizational subsystem was evaluated through interviews of firm owners to identify management perspectives on the available technologies and also on the risks associated with the drywall dust, with the intent of identifying barriers to technology adoption. Through a questionnaire with both scaled and open-ended questions, firm owner perception of the dust risk to productivity, customer satisfaction and worker health were explored, as were reports of frequency of use of the five technologies: respiratory protection, wet methods, pole sanders, ventilated sanders, and low-dust joint compound.

Firm Owner Perceptions of Risk

Perception of risk was evaluated in this study, because it has been identified as a powerful antecedent of risk mitigation decisions (Diaz and Resnick, 2000). Previous research has demonstrated that an intervention designed to alter manager perception of risk can increase the adoption of engineering control technology (Arezes and Miguel, 2005). In a study of the control of worker exposure to asbestos fibers, an association between risk perception and adoption of hazard controls was found (Stewart-Taylor and Cherrie, 1998). However, a large-scale study of the associations between risk perception and risk behavior found that there is no causal relationship between the two, but that they are highly correlated and both influenced by the causal factors of job stress and working conditions (Rundmo, 1996). Rundmo (1996) suggested that measures of risk perception are valuable in their ability to predict the overall level of safety in a work system, but that interventions designed to alter safe practices needed to address the antecedent factors of job stress and working conditions, rather than attempting to alter perception of risk. Therefore, in the present study, a simplified measure of firm owner risk perception was designed to provide a single datum about the current safety status of the drywall finishing industry, regarding dust control. Further research would be necessary to fully characterize the risk perceptions and risk behaviors associated with this industry.

Less than half of the firm owner respondents perceived a serious threat to customer service or productivity, and roughly half perceived a risk to worker health. This figure indicates that owners are not accurately assessing the objective risk to workers. Drywall joint compound has been found to contain crystalline quartz (silica), talc and mica and a previous case study found worker exposures exceeded occupational exposure limits (NIOSH, 2000). Silica, talc and mica are regulated by the Occupational Safety and Health Administration (OSHA) in its standards for the construction industry (OSHA, 29 CFR 1926.55). Considerable educational material regarding the health effects associated with silica has been published by OSHA and NIOSH and targeted to the construction industry audience. In light of this, the firm owner risk perception to worker health is considered to be lower than what would be expected.

An effect of firm size on the reported perceived risk was found, with owners of small firms rating the risk to worker health as more significant than those of larger firms. This finding might be indicative of a power-distance effect, as has been found in previous research on the perception of risk. Social power distribution has been found to impact perception of risk, in that those with less power and control tend to perceive themselves more vulnerable to the risks (Vaughan and Nordenstram, 1991). Agency, or the individual's perception of personal ability to effect change through individual behavior, has been strongly associated with perceptions of risk (Walker et al, 1998). And the number of layers of organizational hierarchy in a work setting has been found to have an impact (Slovic et al, 1993). These studies suggest that those in lower levels of an organizational structure, or those in a work system with a more flattened structure with fewer tiers, will tend to have a higher perception of risks associated with the front-line work of that organization. Therefore, it is possible that in this present study, owners of smaller firms, which were defined as having fewer than 10 employees, are closer to the actual work and the people who perform the work. And, this might lead them to estimate the risk to worker health as being higher than do those who own larger organizations and are more removed from the work. This finding also corresponds to that of another study (Chapter 4), in which worker perceptions of the health risk from drywall dust was high. These workers identified management lack of concern for health protection as a major barrier to the adoption of engineering controls. Additional research is recommended to more fully characterize these patterns among workers and managers of the drywall finishing industry.

Responses to the open-ended questions did reveal that there is an understanding among some in the industry that drywall dust contains silica. Several comments did indicate an understanding of the health risks associated with the dust. Some respondents expressed a desire to reduce the dust and a need for improved methods of control. However, more frequent were responses that indicated a tacit acceptance of the risk as being inherent to the work and, thus, unavoidable. Therefore, the findings of this portion of the study indicate a need to address firm owner perceptions of the risk to worker health associated with drywall dust exposure.

Technology Usage Rates

Respiratory protection is notably the most commonly used method of controlling worker exposure to drywall dust. Firms with union affiliation reported using respiratory protection more frequently than did non-union firms. This is not surprising, since collective bargaining agreements typically contain worker protection requirements. The results for the frequency of use of pole sanders were also high, but are likely artificially inflated, since responses to open-ended questions indicated that the poles are used for reaching overhead areas, and not for the purpose of controlling dust. Many firm owners questioned the effectiveness of the pole sander as a means of protecting workers. NIOSH (2000) has recommended the use of pole sanders for this purpose. And, a recent study found them to significantly reduce the thoracic and respirable dust concentrations in the worker breathing zone, over those generated from basic block sanders (Chapter 3). The ventilated vacuum sanders and low-dust joint compound are used by 40 and 20 percent, respectively, of the firms responding; however this figure is likely inflated, as well. Responses to open-ended questions indicated that some respondents were referring to shop vacuums for post-work clean up or whole-room ventilation, in their affirmative answers. Wet methods were the least preferred, with only 10 percent reporting use, though this is the method suggested by the Association of the Wall and Ceiling Industries in its published guide for finishing gypsum board (AWCI, 1995). These results indicate an over-reliance on the least preferred class of hazard control, personal protective equipment. There is a clear need to increase the use of more effective controls, such as the ventilated sander or low-dust joint compound that do not place the onus of hazard control on the worker.

Content analysis of the comments revealed that many firm owners misunderstand the difference between ambient dust control and dust control to protect workers from exposure. Many comments were made about general dilution ventilation and dust containment systems. Such systems serve to reduce ambient dust levels rather than worker breathing zone concentrations. Several comments indicated that firms take dust control precautions in particular construction settings, such as public schools, hospitals, or buildings containing sensitive electronic equipment. Responses to open-ended questions indicated a belief that new construction situations, with open windows and walls, or with room fans, would not present an exposure risk. When asked about additional methods of controlling dust, respondents mentioned the use of barriers and containment systems, which are designed to prevent dust migration from the work area into other building spaces, but which have no value in protecting workers from over exposure. The emphasis of the respondents making these comments was placed upon protecting building occupants and equipment from dust exposure, rather than protecting workers. These findings indicate a need for educational interventions to increase knowledge of appropriate controls and awareness of the need for effective worker protection controls

Open-ended responses also indicated that workers were provided respiratory protective equipment, but that its use was not consistent. There was a prevailing theme that owners considered it the responsibility of the worker to choose to wear the respiratory protection.

The firm owners did not seem to perceive their own role in the establishment of policies and protocols to improve safety and health of the workforce.

Barriers to adoption

Analysis of the open-ended comments revealed key barriers to the adoption of dust control technologies. For the ventilated sanders, found to be highly effective at reducing worker exposure to dust (Chapter 3), the firm owners identified issues associated with usability, productivity, and the work environment. Usability concerns identified were that the workers would take longer to learn to use the technology and that it would be more difficult to attain the desired surface texture. Also noted were problems associated with the size of the technology and how that would limit maneuverability in small spaces. Also, the power cord was a noted limitation to use of the device for sanding large areas, since it would constrain and limit worker movement. Productivity issues identified were that the workers currently have a level of proficiency with the block sanders and that the more complicated ventilated sanders would require time for learning and skill development. Also, the need to empty dust collection containers and lines was perceived as a hindrance to productivity. Cost issues were also mentioned as barriers; not only for initial purchase, but the mention of equipment theft arose in several comments. A key work environmental factor was mentioned by several respondents, in that the technology requires a power source and this is not always available in locations close enough to the work.

The primary barriers to the use of the low-dust joint compound were that the product is not available in all markets and that it is not familiar to firm owners. Firm owners expressed a need to have more information about the product and the quality of surface and ease of sanding, before committing to switch to its use. The cost of the product was also an issue for the respondents. There were frequent mentions of a lack of incentive to switch to a product that would be more costly.

Pole sanders are currently in use in the industry, but not for the purpose of protecting workers. Respondents questioned their effectiveness as dust control measures, stating that workers are “still covered in dust” after their use.

Comments pertaining to wet methods illustrated a pervasive dissatisfaction with this technology. Most comments pertained to quality of finished surface, productivity, and mess created by the method. The productivity issues centered on the need for frequent re-wetting and rinsing of sponges. Respondents overwhelmingly communicated that this method is infeasible for large-scale finishing work.

Limitations and Future Direction

Several limitations were inherent to the present study. Since this study relies on self-report on a topic with some legal and regulatory risk, there is a possibility of response bias in the data. To control for this, the survey protocol began with an explanation of the study objective and an assurance that only aggregate data would be published. A second limitation stems from the fact that the census population was limited to firms that had membership in large trade organizations, with an associated potential for reduced external validity. Firms that opt to join trade organizations tend to be larger than those without membership. For this reason, the present study included analyses to test for the effects of firm size on findings. Since there was a significant effect of firm size, future research is needed into the trends associated with smaller firms without trade organization affiliation. Finally, there has been considerable discussion in the risk perception literature regarding the reliance on scaled questionnaire instruments for the assessment of risk perception, as summarized by Kristensen (2005). The main arguments have been that a scaled response provides an overly simplistic measure of a highly complex cognitive process. While the present study did employ qualitative measures, in addition to the scaled items, it is understood that the metrics might still lack a degree of depth that would have been obtained through a more holistic and unified approach.

Conclusions

The goal of this research is to provide inputs into the design of an effective intervention strategy to improve drywall finishing worker protection from dust. Inputs of particular importance are the key root causes of the current low adoption rates of the most effective dust control technologies. These barriers will be key inputs into the intervention design (Chapter 5). The primary barriers to the use of the ventilated sanders were concerns over tool usability and productivity. Firm owners expressed concern that workers would not be able to produce the quality work with the efficiency necessary, with the more complicated tool. Additional barriers noted pertained to the work environment. Most importantly, perhaps, is the absence of a power source on many new construction sites. Also, the tool's size could prevent its use in either very small or very large spaces, due to its length and the limitations of the power cord, respectively. The primary barriers to the use of the low-dust mud are the lack of availability and cost issues. Firm owners noted a lack of incentive to switch to a higher cost product. Pole sanders are currently in common use in the industry. They are not used for the specific purpose of worker protection; however that would be an indirect effect. Wet methods, while offering some degree of protection, rated very poorly in this study and in other recent studies of worker perceptions and tool usability (Chapters 3 and 4). Therefore, this method is not recommended by the author as the targeted preferred control method. Ventilated sanders and material substitution with lower-dust-yield joint compound are more promising solutions to this occupational health problem. To improve industry usage rates of these products, primary recommendations are the redesign of the ventilated sanders to address concerns and increase adjustability and an increase in product availability and effectiveness data for the low-dust mud.

Chapter 3: Evaluation of Drywall Sanding Technologies Dust Control and Human-tool Interface

Abstract

Objective: This study evaluated four commercially available drywall sanding tools (block, wet sponge, pole, and ventilated) for dust generation rates and usability and generated tool re-design specifications to improve usage rates.

Methods: Sixteen participants performed simulated drywall finishing tasks with each of the four tools. Outcome measures of interest were thoracic and respirable breathing-zone dust concentrations and the usability metrics of ease of use, ease of learning, perceived productivity, and comfort.

Results: The ventilated, powered drywall sanding tool produced significantly less dust than did the other three tools. The pole sander and wet method produced significantly less dust than the block sander. The block sander performed best in usability evaluations of "ease of learning", "ease of use", and "overall best". Although it was also rated highly in the "overall best" ranking, the ventilated sander performed poorly on the usability metrics, "ease of use" and "perceived comfort". Findings from content analysis were employed in development of re-design recommendations.

Conclusions: Ventilated sanding technology can significantly reduce worker exposure to drywall dust; however, usability problems might be preventing widespread adoption of this technology. Re-design is recommended to improve comfort and ease of use.

Keywords: drywall, dust, construction work, usability, dust control

Introduction

Respiratory disease among plasterers and wall finishers is a public health concern, due to the disproportionately high rates of respiratory disease and disability that these workers experience. Drywall finishing operations have been associated with worker over-exposure to dust that contains known particulate respiratory health hazards, such as silica, talc, and mica (NIOSH, 1997). Despite the existence of engineering, work-practice, and personal-protective-equipment (PPE) control technologies for the mitigation of this hazard, worker exposures persist in the construction industry (Carlton *et al.*, 2003). A recent study found that drywall finishing contractor firms primarily rely upon respiratory protection, rather than more effective methods, to control worker exposure to drywall dust (Chapter 2). In that study, firm owners indicated that workers were supplied with respiratory protection equipment, but that its use was not consistent. The present study aimed to explore, within a Health Belief Model conceptual framework, worker perceptions of the hazards and controls for this occupational dust with the ultimate objective of designing interventions to improve worker protection in this industry.

The National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of worker exposure to drywall dust and potential health effects associated with drywall finishing work during renovation activities (NIOSH, 1997). Respiratory symptoms were found to be common among drywall finishers and tended to improve when workers were away from the workplace. Workers were overexposed to total dust, respirable-fraction dust, and crystalline silica.

There are important gaps in the existing knowledge regarding this occupational health problem. Aside from a pilot project conducted by the National Institutes for Occupational Safety and Health (NIOSH, 2000), there has been no published evaluation of the effectiveness of the different dust control technologies. Additionally, there is a need to identify the causal factors leading to the persistence of worker exposure, despite availability of effective controls. In a separate study, a survey of drywall finishing contractors determined that dust controls are not commonly used in practice (Chapter 2). Once probable causes of low usage rates are identified, intervention strategies can be developed and deployed in order to improve controls usage rates in drywall finishing operations.

One potential explanation of low use of dust control technology lies in a faulty user-tool interface. This study was designed to evaluate issues in the human-technology interface. It also aimed to substantiate the differences in dust generation among the commercially available sanding tools.

Usability is the sub-field of human factors engineering that evaluates a technology to assess the degree to which the design may be used effectively and efficiently by a human (Charlton, 2002). Usability is defined as a composite of several attributes: learnability, efficiency, memorability, error rate, and satisfaction (Hix, 1993). A summative usability evaluation was performed here in order to identify any tool-related factors that might prevent adoption and regular use by end-users. Since the sanding technologies being evaluated in this study are hand-tools, usability metrics previously designed to evaluate hand-tools were employed. In 2001, Miller published guidelines for conducting usability evaluations of hand-tools . Several metrics were identified for assessing hand-tool usability: ease of use, force required, comfort levels, likelihood to drop parts, and physical characteristics of the hand tools. Johnson (1999) described the usefulness of subjective usability evaluations of hand tools for comfort, productivity, and ease of use. In a directly relevant study of usability of orbital sanders, a user-reaction survey evaluated the metrics hand/arm discomfort, force required, productivity, and comfort (Spielholtz, 2001). Therefore, in the current study, a survey of user reactions was used to evaluate the aspects of usability: ease of learning, ease of use, perceived productivity and comfort.

Methods

Participants performed a simulated drywall finishing task in a laboratory setting, with each participant performing the task four times, once with each sanding technology of interest. Dust concentrations, thoracic and respirable size fractions, were measured continuously throughout each sanding session. Following each session, participants completed a usability questionnaire. Following the entire experimental set of four task sessions, participants were asked to complete a questionnaire that assigned a ranking to all four technologies.

Experimental Design:

This experiment was conducted as a mixed-factor design, with one between-subjects factor (gender) and one repeated-measures factor (sanding tool type). The four sanding tools were: block, ventilated, pole, and wet. The dependent variables of interest were time-weighted average breathing-zone particulate concentrations and usabililty metrics. Six dependent variables were measured: thoracic particulate concentration, respirable particulate concentration, ease of learning, ease of use, perceived productivity, and perceived comfort. Presentation order the tools was balanced using a 4 x 4 Latin square design, with two Latin squares for each gender. A total of 16 participants completed the experiment, with equal numbers of males and females.

Apart from the treatment factors, the following sources of potential variation were identified: environmental factors, such as air currents, humidity, and temperature; ambient dust concentration at the start of the experiment; participant prior experience with one or more of the technologies; learning, or carry-over, effects between sanding technology; and individual participant skill differences. To control for environmental factors, the laboratory had fixed levels of temperature, humidity and air currents. To control for ambient dust concentration, a value of dust concentration change, which subtracted the starting concentration from the data-logged concentration values, was used as the outcome measurement of interest. To control for participant prior experience, only novice users were used as participants in the study. To control for individual differences in skill, a randomized complete block design was employed, using participants as blocks. Counterbalancing of treatment condition orders, using Latin Squares was used to control for carry-over effects. The repeated measures design was also chosen in order to allow for the collection of meaningful usability testing data. Having a participant experience all four technologies and evaluate the usability of each, allowed for enhanced usability comparisons.

Participants:

The 16 were recruited from a population of university students. All were above the age of 18 and had no prior experience with drywall sanding tools. Age, ethnic group affiliation, and other demographic factors were not recorded, as they were not factors of consideration in this study. Since all pairwise comparisons among the four sanding technologies were of interest, calculation of the required number of participants was based upon the Scheffé method of multiple comparisons at an overall confidence level of 95%. The confidence interval was selected with the intent of indicating a difference in a pair of treatment combinations, if the true difference in respirable dust concentration levels is at least 3 mg/m^3. This value is 20% of the Occupational Exposure Limit (OEL) established for particulates-not-otherwise-classified, a category that includes the dusts in this study. This is also the mean concentration found in the only existing prior study of drywall dust exposure assessments (NIOSH, 1997). In the NIOSH (1997) study, the standard deviation was found to be 1.98 for drywall finisher dust exposures. From statistical power tables (Kutner et al, 2004), with $\alpha = 0.05$ and $\beta = 0.20$, the number of required blocks (participants) was found to be 16.

<u>Simulated Drywall Finishing Task:</u>

A four-foot-square piece of drywall board was prepared for each research participant. To each board were applied four strips of drywall joint compound (Sheetrock Brand, Lightweight All Purpose Joint Compound, United States Gypsum Company, Chicago, IL). These were applied and allowed to cure, per manufacturer's instructions, by a trained drywall finisher. The board was attached to the wall inside a laboratory enclosure (Fig. 9).

Figure 9: Laboratory enclosure and joint-compound on wall board

Participants were instructed on the use of one of the four drywall sanding tools and asked to sand one joint compound strip for a five minute period of time. They were given the goal of removing as much of the joint compound as possible during the five minute period.

<u>Independent Variables:</u>

Four drywall sanding tools were employed in this study (Figure 10): a block hand sander, a wet sponge sander, a pole sander, and a powered vacuum sander (model 7800, Porter Cable Inc., Cleveland, OH). All four sanding tools had the same level of abrasiveness of the sanding surface (180 grit**). I**t was anticipated that gender differences might exist in the tool usability metrics and that these differences might be important considerations in design recommendations for tool improvement, therefore this variable was used in the experimental design as a between-subject factor.

Figure 10: Sanding technologies: block hand sander, wet sanding sponge, pole sander, ventilated sander

Dependent Variable: Dust Concentration (Thoracic and Respirable).

Drywall joint compound dust concentrations were measured throughout the duration of each drywall sanding task session, using two Dusttrak Sidepak AM510 Personal Aerosol Monitors (TSI Inc, Shoreview, MN). The AM510 is a miniature, battery-operated, laser photometer that measures airborne particulate matter in terms of mass concentration in units of milligrams per cubic meter of air sampled (mg/m^3). Each participant wore two sampling trains involving the AM510 monitors: one that employed a 10-mm Nylon Dorr-

Oliver Cyclone inlet that had a median cut-point of 4.0 micrometers aerodynamic diameter, and one that employed a PM10 Impactor that had median cut-point of 10 micrometer aerodynamic diameter (Figure 11.). These two size classes were chosen because they represent the respirable and thoracic particulate size classes, respectively. These size classes are implicated in the respiratory diseases associated with this occupational task. The sampling train air inlet orifices were attached within a one-foot radius of the participants' mouth and nose (i.e. the breathing zone). The sampling trains were mounted to a waist-belt with suspenders, so that the positioning of the air inlets and AM510's would be consistent on all participants.

Figure 11: Dual Sampling Trains

Flow rates of 1.7 L/min were used in both sampling trains and were calibrated before and after each experimental session, using a DryCal DC-Lite Primary Flow Meter (BIOS Inc, Butler, NJ). A 10 second logging interval was chosen and a calibration factor of 0.90 was used, since that is the recommended factor (TSI, 2005) for the sampling of silica dust, a primary constituent of drywall joint compound. Ambient dust concentrations at the beginning of each sanding task session were measured and subtracted from any following measurements made during the sanding task sessions. The resulting delta concentrations were averaged across the five minute sampling period, to provide a 5-minute-time-weighted-average-delta-concentration (average concentration). This average concentration was the outcome measure used in the statistical analyses.

Dependent Variables:

Usability was evaluated through four metrics: easy of learning, ease of use, perceived productivity and perceived comfort. Each metric had several associated items in a questionnaire (Appendix D). Each questionnaire item had a corresponding Likert-type scale, with relevant verbal anchors (1 = strongly disagree, 5 = strongly agree). Additionally, responses to open-ended questions were analyzed through content analysis procedures, using appropriate coding categories. The metrics, and associated questionnaire items, are listed below (Figure 12):

Ease of learning:

1. I felt that this was easy to learn.
2. It did not take long for me to feel like I was using it correctly.
3. Anyone could learn to use this quickly.

Ease of use:

4. I felt that this was easy to use to do this sanding.
5. I did **not** feel frustrated while using this technology.
6. I would choose to use this sanding tool, if I had to perform this task in real life.
7. I didn't have any problems while using it.

Perceived productivity:

8. I felt like I could get the sanding done quickly with this technology.
9. I felt like I could get the sanding done correctly while using this technology.

Ease of use:

10. I felt comfortable while using this technology.
11. I did not have to apply a lot of force to accomplish the sanding task.
12. My hand/arm felt comfortable during this task.

Figure 12: Usability Metrics and Questionnaire Items

After the four sanding sessions, participants completed another questionnaire that asked them to rank-order the tools according to the following scale: 1 = Best, 2 = Second Best, 3

= Third Best, and 4 = Worst. This ranking was done separately, based on three criteria: “Easiest to Use”, “Easiest to Learn”, and “Overall Best”. Open-ended questions solicited input on the tools selected as “overall best” and “overall worst”.

Procedures

Before participants entered the lab, several preparatory actions were undertaken. The AM510’s were calibrated to ensure an air flow rate of 1.7 L/min and were zeroed. The wallboard panels were placed on the wall mount in the experimental enclosure. Fresh sanding screens were installed on sanding tools. Upon arriving at the lab, participants reviewed and completed informed consent forms, received brief training on the use of protective equipment and an overview of the project methods. They were then fitted with a NIOSH-approved N-100 filtering facepiece, goggles, gloves, ear muffs, and the sampling train harness. After reviewing task parameters for the trial, the participants entered the sanding chamber with the first sanding tool, the AM510’s recording session was initiated, and a timer was set for five minutes. Participants sanded for the five-minute period and then the AM510’s recording was paused, while the participants completed the usability questionnaire for that tool just used. Four sessions proceeded according to this protocol, until all tools had been used. Then, a final ranking questionnaire was completed and the participants were compensated $10/hour for their time.

Analysis

A mixed-factor MANOVA was used, with one between-subjects factor (gender) and one repeated-measures factor (tool type) and all six dependent variables. Student’s t test or Tukey’s HSD were used to perform all post-hoc comparisons of means. To further investigate simple effects, subsequent to a finding of a significant MANOVA effect, repeated-measures univariate ANOVA was used to test for differences in respirable and thoracic dust concentrations across tool types. Similarly, repeated-measures univariate ANOVA was used to test for differences among tool usability scores, across tool type. Ranking scores for each usability metric were analyzed using a one-way analysis of variance (ANOVA) repeated-measures design All statistical analyses were performed using JMP® 6.0.2 (SAS Institute Inc., Cary, NC), with significance determined when $p < 0.05$.

Open-ended question responses were analyzed using content analysis methods (Krippendorff, 2004). Codes that were both exhaustive and mutually exclusive were established for the set of open-ended responses, by the researcher. Codes were created that mapped back to the research questions pertaining to usability metrics (Table 12). An additional code was assigned to denote whether the coding unit was positive or negative. For example, a comment about comfort might have indicated the equipment was comfortable (positive) or that it was uncomfortable (negative). Written responses to open-ended questions on the questionnaires were unitized by the researcher. Coding units were defined as sentences or groups of sentences connected on a unifying thought. The entire set of coding units and assigned codes is included in Appendix G. Codes were assigned to responses by two independent coders with education in conducting human factors research, and who had been trained by the researcher on the particular coding definitions and process. Inter-rater reliability was calculated for each set of codes, using Krippendorff's alpha, with significance set at $\alpha = 0.8$ (Krippendorff, 2005). Only coding units with rater agreement were included in the analysis. Frequencies of occurrences of codes were the main metrics of interest.

Table 12: Code Definitions for Content Analysis

Code	Code Definition
Ease of Learning (EL)	Comments that pertain to the user's ability to begin using the technology. Comments that pertain to the user's ability to arrive at a feeling of proficiency while using the technology.
Ease of Use (EU)	Comments that pertain to the user's ability to accomplish the task as instructed, once familiar with the technology.
Perceived Productivity (PP)	Comments that pertain to the user's perceived ability to employ the technology to accomplish a set amount of work in a given unit of time. Comments that pertain to the user's perceived ability to employ the technology to accomplish a desired quality level of work in a given unit of time.
Perceived Comfort (PC)	Comments that pertain to the user's observations of physical sensation: pain, fatigue, muscle stress or strain, or lack thereof.

Results

Gender

In a mixed-factor analysis containing all dependent variables (dust concentrations and usability scores) the Gender x Tool interaction was significant ($F(13, 50) = 2.594$, $p = 0.0079$). The main effect of tool type was significant ($F(13,50) = 26.99$, $p < 0.0001$), but the main effect of gender was not ($F(1,62) = 2.02$, $p = 0.160$).

Dust Concentration

The mixed-factor MANOVA with all dependent variables revealed a significant multivariate effect for type of tool (Wilk's lambda = 0.104, $F(42,140)$, $p< 0.0001$). Subsequent univariate ANOVA indicated significant differences between tool types for respirable dust concentration ($F(3, 60) = 23.53$, $p <0.0001$) and thoracic dust concentration

(F(3,60) = 14.93, p <0.0001), as illustrated in Figures 13 and 14. The ventilated, powered drywall sanding tool produced significantly less dust than did the other three tools. The pole sander and wet method produced significantly less dust than the block sander.

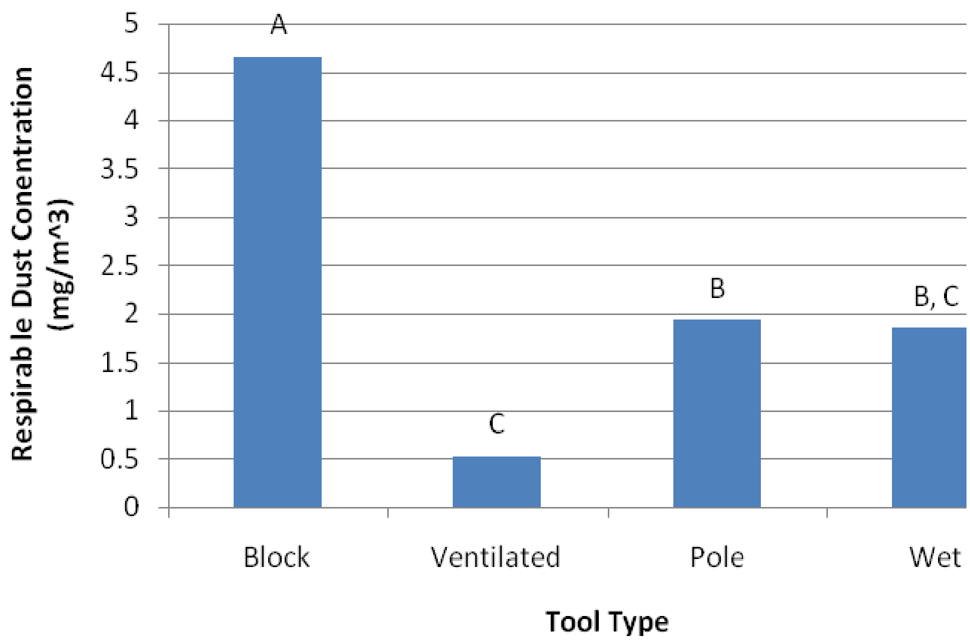

Figure 13: Respirable Dust Concentration by Tool.
Tukey's HSD Means Comparisons for All Pairs (Tools not assigned same letter are significantly different)

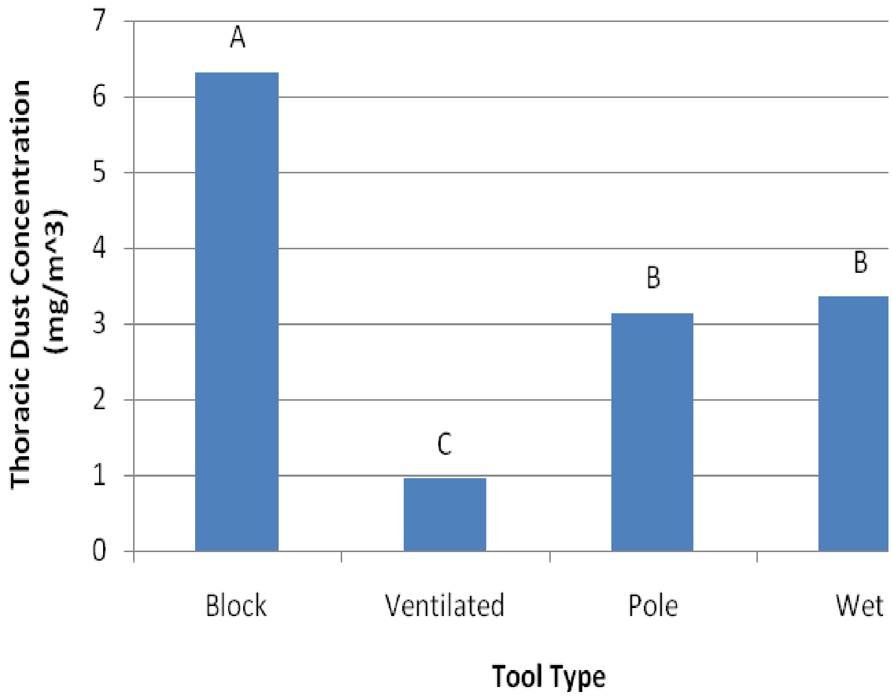

Figure 14: Thoracic Dust Concentration by Tool
Tukey's HSD Means Comparison for All Pairs (Tools not assigned same letter are significantly different)

<u>Usability:</u>

The mixed-factor MANOVA with all dependent variables revealed a significant multivariate effect for type of tool (Wilk's lambda = 0.104, F(42,140), p< 0.0001). Subsequent univariate ANOVA showed significant differences between tool types for ease of learning question #2 (F(3, 60) = 4.21, p = 0.009), ease of learning question #3 (F(3, 60) = 3.90, p = 0.012), ease of use question #7 (F(3,60) = 3.76, p = 0.015), and perceived productivity question #8 (F(3, 60) = 9.39, p < 0.0001). These findings are depicted in Figures 15 – 18. There were no other significant differences found. Notably, therefore, none of the perceived comfort scores were found to be different across tool types.

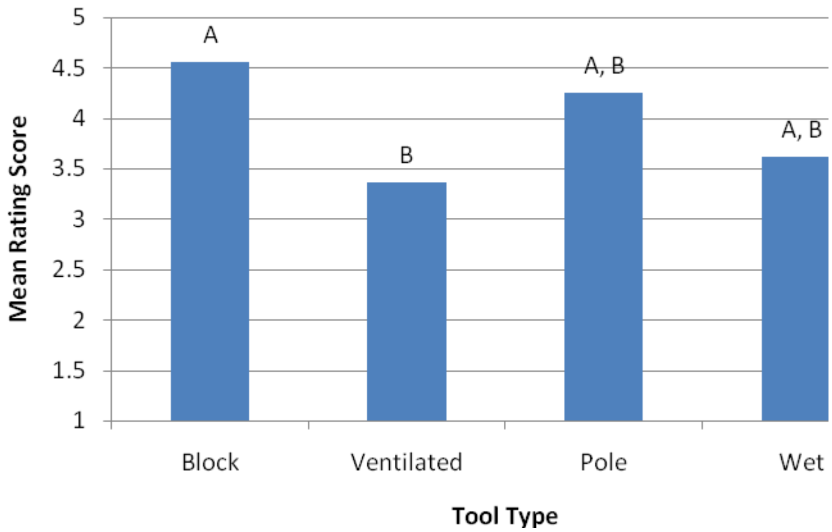

Figure 15: Mean score for question #2: "It did not take long for me to feel like I was using it correctly."
Likert scale anchors: 1 = strongly disagree, 5 = strongly agree.
(Tukey's HSD all pair wise comparison of means. Bars not assigned same letter are significantly different)

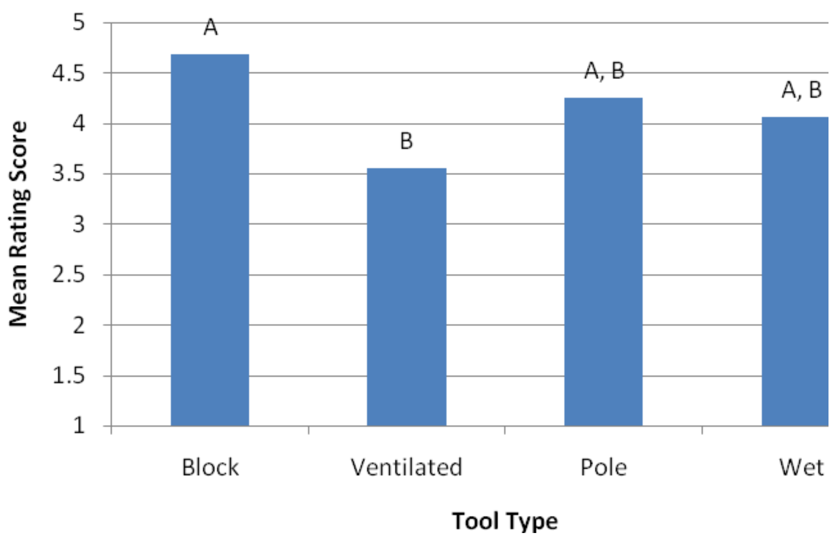

Figure 16: Mean score for question #3: "Anyone could learn to use this quickly."
Likert scale anchors: 1 = strongly disagree, 5 = strongly agree.
(Tukey's HSD all pair wise comparison of means. Bars not assigned same letter are significantly different)

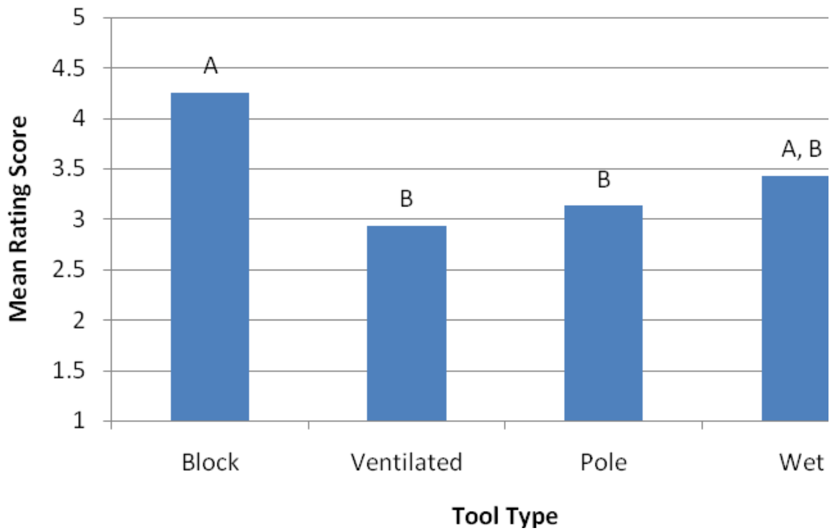

Figure 17: Mean score for question #7: "I didn't have any problems while using it."
Likert scale anchors: 1 = strongly disagree, 5 = strongly agree.
(Tukey's HSD all pair wise comparison of means. Bars not assigned same letter are significantly different

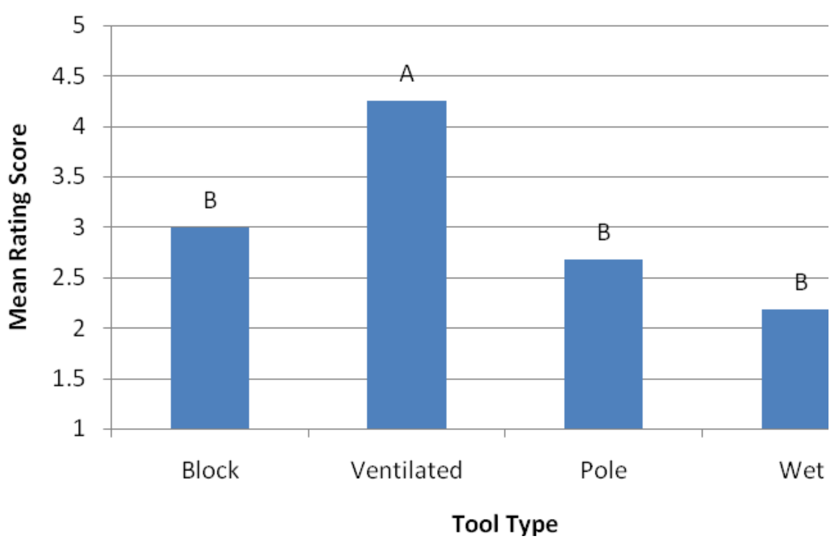

Figure 18: Mean score for question #8: "I felt I could get the sanding done quickly with this technology."
Likert scale anchors: 1 = strongly disagree, 5 = strongly agree.
(Tukey's HSD all pair wise comparison of means. Bars not assigned same letter are significantly different

Usability Rankings

Mean ranking scores are summarized in Table 13. ANOVA revealed a significant effect of tool type on rankings of "easiest to learn" ($F(3, 45) = 7.59$; $p = 0.0003$), and a significantly better ranking for the block sander, when compared to all other tool types (Figure 19). There were no significant differences found among "easiest to use" rankings. ANOVA of the "overall ranking" scores did reveal a significant effect of tool type ($F(3, 45) = 6.007$; $p = 0.0016$); scores for the block sander and ventilated sander were significantly higher than those of the wet method and pole sander (Figure 20). There were no discernable differences between the block sander and ventilated sander in terms of their scores in the "overall best" ranking.

Table 13: Mean Usabilty Rankings by Tool Type
(scale: 1 = best, 2 = second best, 3 = third best, 4 = worst)

Tool	Mean Score (SD) "Easiest to Learn"	Mean Score (SD) "Easiest to Use"	Mean Score (SD) "Best Overall"
Block	1.43 (0.63)	1.94 (0.93)	2.00 (0.81)
Ventilated	3.18 (0.98)	2.65 (1.32)	1.81 (1.11)
Pole	2.75 (0.93)	2.88 (0.96)	3.06 (0.93)
Wet	2.63 (1.15)	2.63 (1.15)	3.12 (1.02)

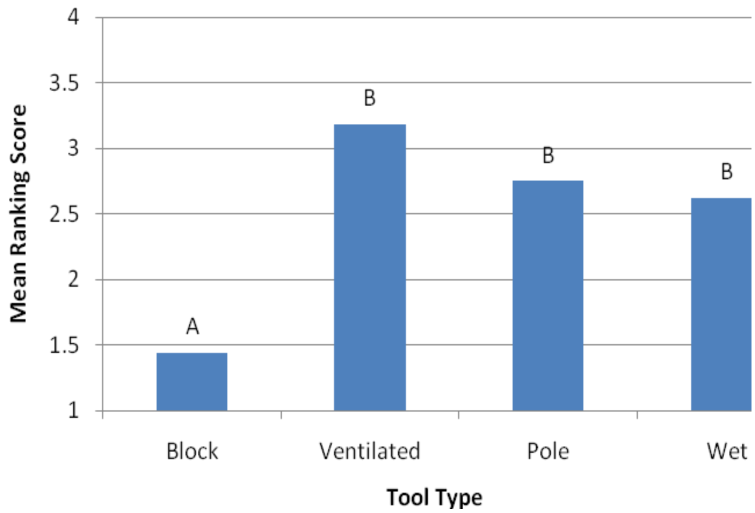

Figure 19: Ranking scores for "Easiest to Learn"
(anchors: 1 = Best, 4 = Worst)
Tukey's HSD Means Comparisons for All Pairs (Tools not assigned same letter are significantly different)

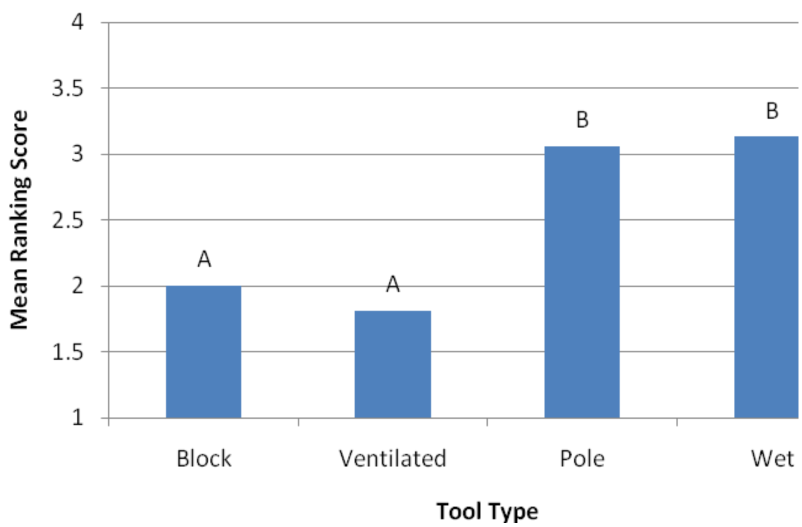

Figure 20: Ranking scores for "Overall Best"
(anchors: 1 = Best, 4 = Worst)
Tukey's HSD Means Comparisons for All Pairs (Tools not assigned same letter are significantly different)

Usability Open-Ended Content Analysis

Frequency counts of positive and negative coded units are summarized in Table X, according to usability metric, tool, and gender of respondent. Positive and negative comment for each usability metric are also depicted graphically, in Figures X – X.

For the Ease of Use metric, the block sander received more positive comments than did the other three technologies, and fewest negative comments. Participants noted that there was more manual control of the device, in terms of maneuverability and degree of pressure applied to the joint compound surface. Also, it was noted that participants were closer to the work and could examine the progress of the sanding task, as compared to the pole and ventilated tool. The pole and wet method received substantially more negative comments on this metric than did the other two tools. In fact, with 21 and 25 comments, respectively, negative feedback on the ease of use of the pole and wet method were the most commented upon categories in the entire set of open-ended questions. For the pole, several comments were made regarding the swivel-joint at the connection between the sanding pad and the pole. This made the tool difficult to maneuver, for several of the respondents. Also, the work surface was removed from the participants' visual field, which made it difficult for them to monitor quality and progress. The wet method received several unfavorable comments about the moisture causing the joint compound to clump. Also, that it was more difficult to obtain a smooth surface with this method. Participants also commented on the mess resulting from the dripping water/dust slurry.

Ease of Learning received few written comments, overall. Comments indicated that participants struggled with the ventilated sander in the beginning of the task. Comments indicated that the amount of water used in the wet method and the frequency of rinsing were confusing to participants. The ventilated sander and the pole performed poorly on the construct of "perceived comfort", especially among female participants. Of 17 negative comments made about the ventilated sander, 16 of them were made by female participants. Most had to do with the weight of the device and overall length. Several female participants noted that the tool was too large for a person their size to use effectively or for any period of time. Many mentioned hand/arm comfort associated with the ventilated sander. Several participants noted that it was difficult to change positioning of their hands during the task and that this contributed to fatigue. The pole sander also received many negative comments concerning comfort. Participants noted that it was difficult to apply the necessary pressure to the sanding surface, given the pole length and angle. The block sander had the most positive comments about comfort. Many mentioned it's light weight and handle. Many favorable comments were made about the ability to apply appropriate pressure to the sanding surface and switch hand positions to avoid fatigue.

On "perceived productivity", the ventilated sander performed best, receiving more positive comments in the open-ended questions. Many noted that it took far less time to accomplish the task with the powered, ventilated sander. Several comments noted that this tool would make large-scale sanding jobs more efficient. The wet method had the greatest number of negative comments pertaining to this metric. Many comments noted that this method would make a large-scale sanding project highly inefficient. The need for frequent rinsing of the sponge was the most commonly listed complaint regarding productivity. The pole sander received no positive comments. Female participants assigned low scores to the pole sander and wet method on the question of speed of task accomplishment.

Table 14 provides a summary of all units and codes assigned. A summary of all findings for this study is provided in Table 15, below.

Table 14: Number of Written Comments for Each Code and Category

Code	Category	Description	Block Total	Block Female	Block Male	Ventilated Total	Ventilated Female	Ventilated Male	Pole Total	Pole Female	Pole Male	Wet Total	Wet Female	Wet Male
EU	Ease of Use Positive	Comments that pertain to the user's ability to begin using the technology. Comments that pertain to the user's ability to arrive at a feeling of proficiency while using the technology.	10	8	2	5	3	2	6	2	4	7	5	2
	Ease of Use Negative		6	5	1	9	5	4	21	15	6	25	10	15
EL	Ease of Learning Positive	Comments that pertain to the user's ability to accomplish the task as instructed, once familiar with the technology.	0	0	0	0	0	0	0	0	0	0	0	0
	Ease of Learning Negative		0	0	0	2	2	0	0	0	0	0	2	2
PC	Perceived Comfort Positive	Comments that pertain to the user's perceived ability to employ the technology to accomplish a set amount of work in a given unit of time. Comments that pertain to the user's perceived ability to employ the technology to accomplish a desired quality level of work in a given unit of time.	6	5	1	1	1	0	1	1	0	2	6	1
	Perceived Comfort Negative		10	6	4	17	16	1	13	9	4	2	1	1
PP	Perceived Productivity Positive	Comments that pertain to the user's observations of physical sensation: pain, fatigue, muscle stress or strain, or lack thereof.	3	3	0	10	8	2	0	0	0	1	1	0
	Perceived Productivity Negative		3	1	2	3	2	1	2	2	0	10	8	2

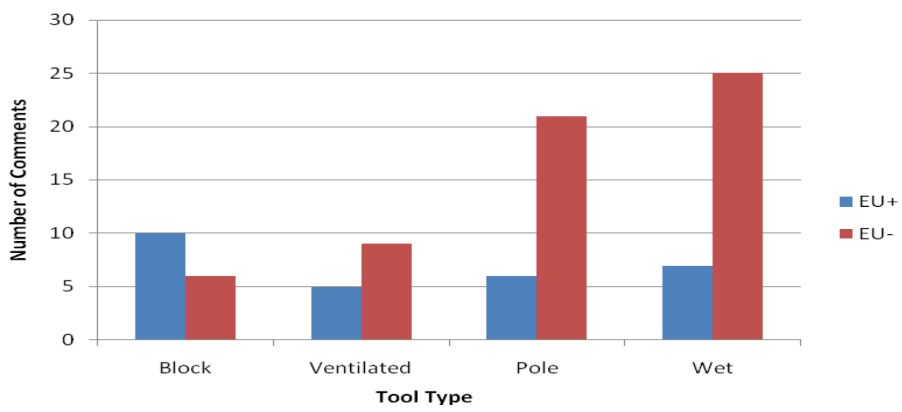

Figure 21: Positive and negative "Ease of Use" comments from open-ended questionnaire items

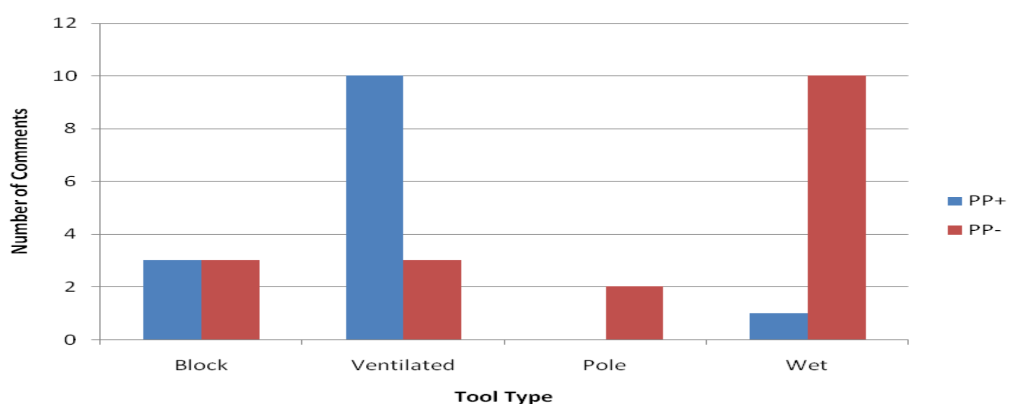

Figure 22: Positive and negative "Productivity" comments from open-ended questionnaire items

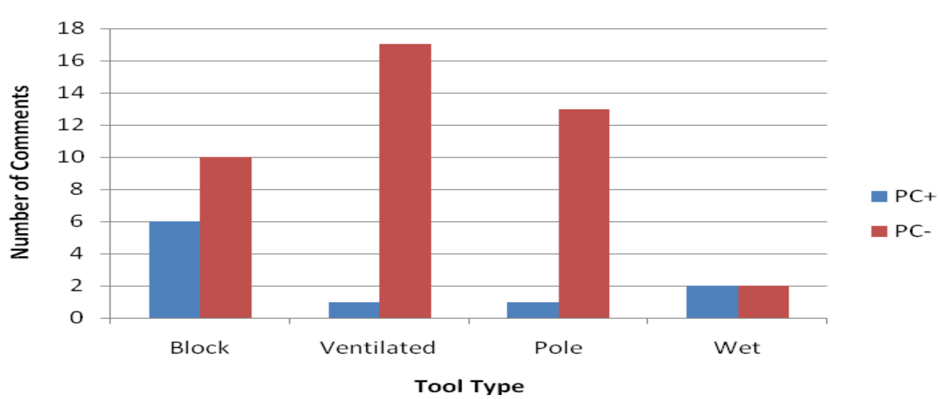

Figure 23: Positive and negative "Perceived Comfort" comments from open-ended questionnaire items

Table 15: Summary of Findings

1. **The powered, ventilated sander produces less dust than other methods.**

   a. The ventilated sander produced less thoracic-size-class dust than the other three methods.

   b. The ventilated sander produced less respirable-size-class dust than the pole sander and the block sander methods.

2. **The block sander produces more dust than other methods.**

   a. The block sander, the current industry standard tool for drywall finishing work, produced more dust in the worker breathing zone than the other three methods.

   b. The block sander produced more dust in both respirable and thoracic size classes.

3. **The wet method and the pole sander offer some degree of worker protection, compared to the block sander.**

   a. The wet method, recommended by AWCI, produced less dust in the worker breathing zone, in both respirable and thoracic size classes, than did the traditional block sander.

   b. The pole sander, recommended by NIOSH to reduce breathing zone concentrations, did produce less dust in the breathing zone in both size classes, than did the traditional block sander.

4. **The block sander performs best in usability analysis.**

   a. The block sander performed best in the usability metric "ease of learning".

   b. The block sander and ventilated sander tied for top rank in the usability metric "overall best"

   c. On the usability construct "ease of use" analysis, the block sander received more positive comments and fewer negative comments than did the other three methods.

5. **The powered, ventilated sander performs poorly in usability analysis.**

   a. On the usability construct "perceived comfort" analysis, the ventilated sander received considerably more negative comments and fewer positive comments than did the other methods, especially from the female study participants.

   b. On the "ease of use" usability construct, the ventilated sander received lower scores than did the block sander or the wet method and received fewer positive comments than did the other three methods.

   c. Barriers to industry adoption of this technology may lie in interface problems associated with comfort and ease of use.

Discussion

The present work is part of a larger effort to identify barriers inherent to the drywall finishing work system that are preventing the use of available dust control technologies. In this larger project, each subsystem of the work system is evaluated to identify key causal factors. In this study, the technological subsystem was evaluated through a lab-based experiment of technology effectiveness and usability, with the objective of identifying the best method of reducing breathing-zone dust concentration and barriers to adoption of that technology.

The ventilated sander produced significantly less dust in the thoracic size class than did all the other sanding technologies and less dust in the respirable size class than did the pole and block sander. These findings are consistent with previously published case study data that reported that ventilated sanders reduced worker exposure by 80% and 97%, on separate trials (NIOSH, 2000). In the present study, the ventilated sander reduced participant dust exposure by 89% in the respirable size class and 85% in the thoracic size class, when compared to the block sander. Since the block sander is the current industry standard tool for drywall finishing, it can be said that use of ventilated sanders could reduce occupational exposure by 85% to 89%.

The wet method produced significantly less dust in the respirable size class than did the block and pole technologies. And, it produced significantly less thoracic sized dust than did the block sander. This finding is also consistent with the previous NIOSH (2000) Health Hazard Evaluation that indicated wet methods reduced worker exposure. Also, it supports the AWCI (1995) recommendation of this method for dust control purposes.

The pole sander produced significantly less dust in both size classes than did the block sander. This finding is consistent with a previous study by NIOSH (2000) that stated that pole sanders reduce breathing zone concentrations of dust.

The block sander, the tool used most commonly in drywall finishing industrial practice, produced significantly more dust in both size classes compared to the other three technologies. Therefore, worker exposure to drywall dust can likely be substantially reduced if ventilated, pole, or wet method techniques were used in practice.

Based on the present results, a ventilated sander is the tool recommended by the author for use in the drywall finishing industry. The pole sander and wet method, despite findings of their effectiveness in reducing dust concentrations, are not recommended. While the wet method did reduce dust in the respirable size class, it was not as effective in the thoracic size class. The pole sander was less effective in both particle size classes than was the ventilated sander. Also, both performed very poorly in the usability portion of the study.

A recent study of industry usage rates of these technologies (Chapter 2) found that 15.9% of firms reported using ventilated sanders always and 24.2 percent reported using them often. This finding indicates that nearly 60% of firms are not using the technology on a regular basis. Furthermore, these usage rate findings were likely artificially inflated. Open-ended follow-up questions found that some respondents were referring to the use of shop vacuum cleaners for post-sanding dust removal, or to room ventilation fans, in answering that question. So, in all likelihood, far fewer than 40% of firms are using ventilated sanders on a regular basis.

The purpose of this study was to identify potential problems with the tool-human interface that might be serving as barriers to technology adoption in the industry. In fact, the usability portion of the study did find several key factors associated with the ventilated sander that made use more difficult or less comfortable.

Issues with the size, weight and configuration of the tool were noted frequently in the open-ended portion of the usability study. The sanding unit is mounted at the end of a long pole. This configuration effectively creates a large moment arm, which in turn creates a moment about the shoulder of the worker. Responses to open-ended questions about comfort indicated that participants were experiencing discomfort in the shoulder after a five-minute sanding task. Further study is recommended into the biomechanics associated with this technology and specific parameters for redesign. The pole is not removable and the length is not adjustable. This pole would serve a purpose when the worker needed an extended reach to accomplish a sanding task, however, much sanding is done within arm's length of the worker. Adjustability is recommended in this feature of the technology. The pole length could be made adjustable through a telescoping feature or it could be entirely removable and attached only when needed. Further, the sanding head weight could be reduced to reduce the moment about the shoulder.

Issues associated with the design of the orbital sanding interface were also noted. The orbital disc's rotation and circular shape were mentioned by participants. There was concern that the rotation would create grooves in the finished surface and make maneuverability difficult in certain situations. There were also comments that the circular sanding face would not be useful in corners or along straight edges. Therefore, a suggestion for redesign with a rectangular oscillating sanding pad, rather than an orbital disc, is recommended.

A related complaint concerned the human ability to have a good visual field of the work surface. Participants commented that the long pole and the large orbital sanding face created barriers to task accomplishment. It was difficult to see the quality of the sanding task in the current tool configuration, because of these factors.

All of these findings are supported by those of the earlier study of firm owner perceptions to the barriers associated with this technology (Chapter 2). In that project, firm owners stated as a major barrier their concerns over tool usability and its effect on finished work quality. Several of the same themes emerged from the open-ended portion of that project, as well.

Based on the findings of this summative usability evaluation, the following guidelines have been developed for the re-design of this technology for improved use in the drywall finishing industry (Table 16.). Future research is recommended to develop and conduct iterative usability analysis of prototypes for new configurations of this sanding technology.

Table 16: Design Guidelines for Powered Ventilated Drywall Sander

Usability Construct	Study Findings	Design Recommendations
Ease of Use	Awkward	Make pole removable or adjustable in length
	Rotation of sanding head created problems with maneuverability	Oscillating sanding surface
	Long pole made it difficult to sand at head-height, or below	Add adjustability to pole length; Removable pole to be used only when needed
	Could not see work area	Sanding unit as a hand-held device; add adjustability to pole length; Removable pole to be used only when needed
	Could not maneuver in small spaces	Sanding unit as a hand-held device; add adjustability to pole length; Removable pole to be used only when needed
	Cord/vacuum hose got in way	Coiled, retractable hose
Perceived Comfort	Too heavy	Sanding unit as a hand-held device; add adjustability to pole length; Removable pole to be used only when needed; Use of light—weight polymeric materials; reduce size of sanding head
	Fatigued arms, shoulders, chest	Sanding unit as a hand-held device; add adjustability to pole length; Removable pole to be used only when needed; Use of light—weight polymeric materials; reduce size of sanding head
	Difficult to grip	Change diameter of pole to accommodate twenty-fifth percentile male anthropometry
	Difficult to change hand position	Add adjustability to pole length; Removable pole to be used only when needed; Change position of controls on pole to allow for movement of hands along pole
	Loud	Dampen vibration in sanding head; use polymeric materials; muffle vacuum

Limitations

One primary limitation stems from the laboratory nature of this study. While such studies are more robust regarding internal validity, they are weaker in terms of external validity. . Additionally, in order to control for prior experience with drywall sanding technology, novice users served as study participants. Again, this will yield results that are less externally generalizable. However, since the purpose of this study is to evaluate the technological subsystem, then the choice to avoid the use of skilled drywall finishers served to reduce confounding error that might arise from mixing the worker subsystem into this study. Additionally, it was the author's intention to use the results of this study to in future research that will involve actual construction field worksites. These highly controlled data will provide a foundation for future field research.

While the standard method of conducting usability testing is to use participants who most closely represent the target user population, this study used participants who did not meet this criterion. Participants were recruited from a university student population, while the target user population for drywall sanding technology would be people who are employed in construction trades. The decision to use non-representative participants was carefully considered and deemed appropriate because of the importance of minimizing any confounding error arising from previous experience with drywall sanding technology. Another limitation arose from the selection of participants. While participants were required to have no prior experience with drywall sanding, it had not been required that they have no knowledge of usability or human factors engineering. Several of the study participants were students of human factors engineering and, therefore, had knowledge of several of the underlying principles of the study. This might have led to more expert analysis of the equipment usability constructs than was desired and might have contributed to some bias in the usability results.

Conclusions

A ventilated sander is recommended for the control of worker exposure to dust during drywall finishing operations. This recommendation is made based on the significantly better performance in terms of reducing dust concentrations in the worker breathing zone. Important usability issues were revealed pertaining to “ease of use” and “perceived comfort” in this study and should be addressed by tool manufacturers. Improved tool design would remove the usability barriers that might be preventing consistent use of this technology in the drywall finishing industry.

Chapter 4: Evaluation of Worker Perceptions

Dust Risk and Dust Control Associated with Drywall Finishing Operations

Abstract

Objective: Explore worker perceptions of risk associated with drywall dust exposure and perspectives on dust control options and barriers to their adoption.

Methods: Drywall finishing workers participated in semi-structured, in-depth personal interviews. Interviews were transcribed and analyzed using content analysis procedures. Attitudes and perceptions toward dust control technologies were solicited, and emergent themes were explored. The Health Belief Model, a health promotion model to describe individual perceptions of risk, benefits, and barriers associated with a given health behavior change, served as the framework for understanding workers' readiness to adopt control technology.

Results: Workers tended to perceive a risk to health associated with the dust; however assessments of personal susceptibility to disease were low. Barriers associated with ventilated sanders were identified as being associated with organizational and cost factors. Participants overwhelmingly commented that pole sanders and wet methods are not practical methods for drywall finishing or dust reduction. Participants noted several barriers to the use of respiratory protection equipment, primarily related to comfort and usability.

Conclusions: Future interventions to improve use of effective dust control technologies in the drywall finishing work system could be aimed at increasing individual perception of susceptibility and also at addressing organizational factors that lead to low use of ventilated sander technology.

Keywords: drywall, dust, construction work, dust control, Health Belief Model, perception of risk

Introduction

Drywall finishing operations have been associated with worker exposures that exceed published occupational exposure limits for dust that contains known particulate respiratory health hazards, such as silica, talc, and mica (NIOSH, 1997). Despite the existence of engineering and work-practice control technologies for the mitigation of this hazard, these controls are not in frequent use and worker exposures persist in the construction industry (Carlton *et al.*, 2003). A recent study of frequency of dust controls usage in drywall finishing operations revealed an overreliance upon personal protective equipment and an underutilization of pole sanders, wet methods, and ventilated sanders (Chapter 2).

Occupational exposure to dust is a public health concern, because workers in the drywall finishing trade suffer from disproportionately high rates of respiratory disease. Several recent large-scale epidemiologic studies have found associations between drywall finishing work and the morbidity and mortality of respiratory disease. In a study of proportionate mortality patterns for male construction workers in North Carolina, Wang et al. (Wang *et* *al.*, 1999) found a significant cancer risk for painters, plasterers, paperhangers, and drywall workers. This group had significantly elevated proportionate mortality ratios (PMRs) for malignant neoplasm of the pharynx (PMR = 178), of the trachea and bronchus (PMR = 118), and pneumoconiosis/other respiratory disease (PMR = 152). Specifically, drywall finishers and laborers were found to have a statistically elevated risk of death from cancer of the pharynx (PMR = 133) and lung (PMR = 110), and respiratory tuberculosis (PMR = 675). In an epidemiologic study specific to the plastering trade, PMRs and PCMRs were calculated, using United States death rate information, for all 99 causes of death listed for the 12,873 members of the Operative Plasterers' and Cement Masons' International Association who died between 1972 and 1996 (Stern *et al.*, 2001). Among plasterers, significant elevated mortality was observed for lung cancer and for benign neoplasm. Kaukianen et al. (2005) found that construction painters experience a high prevalence of symptoms of upper-airway disease and that this prevalence was significantly higher than that of other construction-related trades' workers. These authors indicated that exposure to drywall compound dust may be a significant contributing factor in this trend. In the most exhaustive industrial hygiene assessment to date of construction worker chemical exposures, Verma et al. (2003) found that airborne particulate matter was the most prevalent hazard class.

The National Institute for Occupational Safety and Health (NIOSH) published a case study of worker exposure to drywall dust and potential health effects associated with drywall finishing work during renovation activities (NIOSH, 1997). The HHE found that respiratory symptoms were common among drywall finishers and tended to improve when workers were away from the workplace. Workers were overexposed to total dust, respirable-fraction dust, and crystalline silica.

To control occupational health hazards, there are three categories of controls: engineering, administrative, and personal protective equipment.   Engineering controls are preferred because they eliminate or reduce the hazard and do not burden the worker. Personal protective equipment is the least preferred, because of the physiological burden it places on the worker. Engineering and personal protective equipment technologies exist for the control of worker exposure to dust from construction drywall finishing operations. These controls are primarily vacuum sanding, wet sanding, pole sanding, low-dust joint compound and respiratory protection.

Previous studies found that the ventilated sanding technology is highly effective, capable of reducing worker exposure by 85 to 89% (Chapter 3) , but that the of the usage rate of these technologies in the drywall finishing industry is currently low (Chapter 2). Drywall firm owners reported in this study that they rely primarily on respiratory protection to prevent worker exposure to dust. In those previous studies, barriers to technology adoption were described, as identified by firm owners and by usability study participants.

The perspective of drywall finishing workers regarding barriers to technology adoption is the subject of the current study. In order to identify barrier to the use of the effective control technology, it is essential to evaluate the personnel subsystem of the work system. Of particular interest are the worker's perceptions of risk to health associated with occupational exposure to drywall dust, as well as their understanding of the barriers that are preventing widespread adoption of controls in their industry. To evaluate these questions, the Health Belief Model (HBM: Figure 24) served as a theoretical framework. The HBM (Rosenstock, 1960) was developed to describe the cognitive and behavioral processes related to volitional health behavior: the decision to engage in health-risk, health-compromising, or health-protective behaviors. Also important is an understanding of the various individual, familial, social and cultural factors that influence the adoption and maintenance of health-compromising or health-protective behavior.

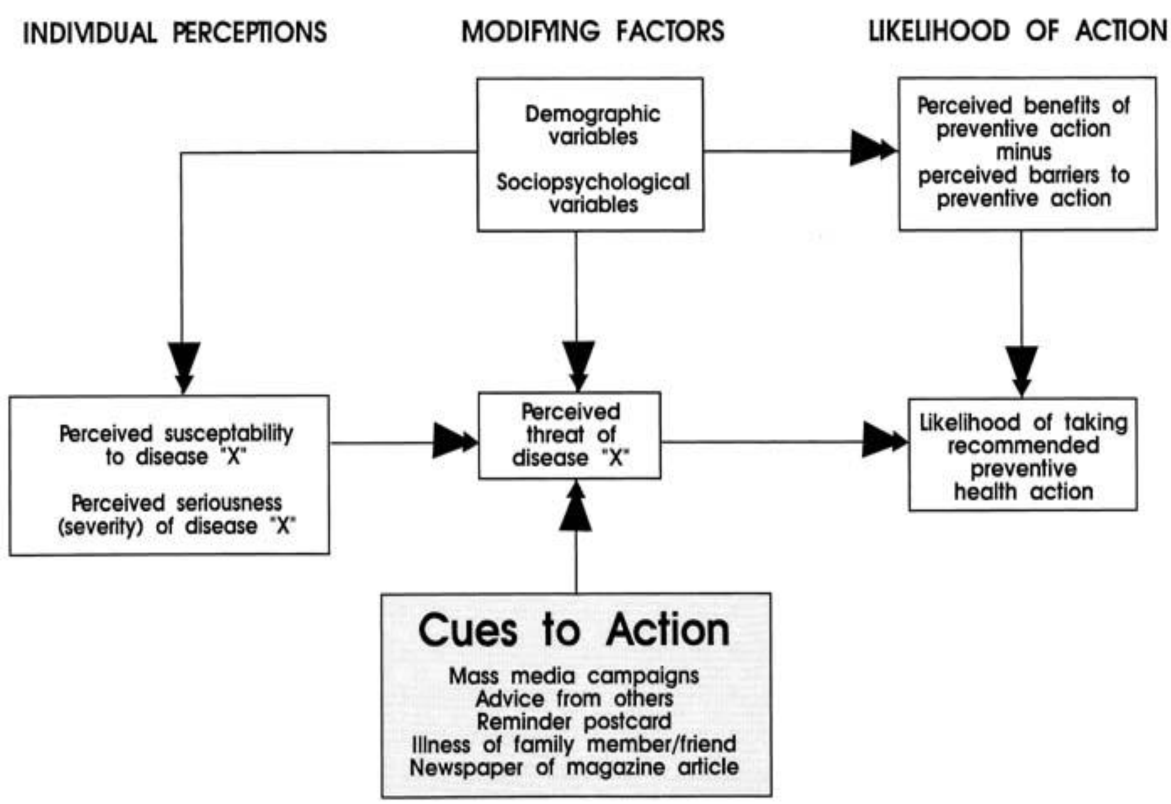

Figure 24: The Health Belief Model (adapted from Rosenstock, 1960)

For five decades, the HBM has been one of the most widely used conceptual frameworks in the study of health behavior. The HBM has been used to explain both adoption (compliance) and maintenance (adherence) of behavior change. It has been employed in various configurations of the original model developed by social psychologists in the U.S. Public Health Service in the 1950's (Hochbaum, 1958; Rosenstock, 1960). There is substantial empirical support for the constructs of the model and their performance in predicting health behavior. "Perceived barriers" has been found to be the strongest single predictor in the model (Janz, 1984). Therefore, the HBM was chosen as an apt model for describing the barriers to the adoption of dust control technologies in this study.

This conceptual framework has been employed in studies of occupational health. A study of volitional health behaviors to prevent exposure to severe acute respiratory syndrome (SARS), the Health Belief Model was used to describe perceived barriers and benefits to the use of a facemask during the performance of high-risk occupational tasks (Wong & Tang, 2005). An evaluation of Mexican workers' use of hearing protective devices found that self efficacy and perceived health status were directly influencing the decision to use the devices (Kerr *et al.*, 2002). Another study used the model to design an intervention to improve the rates of use of hearing protection devices among agricultural workers (McCullagh *et al.*, 2002), and found that interpersonal and situation factors were primary barriers to use and were targeted in the intervention strategy.

This study employs qualitative methods to explore worker perceptions and attitudes regarding the hazards of the dust associated with their work, the available dust control technologies, and constructs of the HBM as they apply to this situation.

Methods

Participants were recruited from firms in the local (Southwest Virginia) drywall finishing industry. Potential participants were required to have a minimum of six months of work experience in the trade, and be employees of a contracting firm, rather than subcontractors or sole proprietors. This was a requirement for inclusion, since *employee* perceptions were of interest in this study (firm owner perceptions were addressed in Chapter 2). Participants were included until saturation of themes was reached. Specifically, saturation occurs when new in-depth interviews do not produce any new themes or codes, but rather repeat themes and codes of previous interviews (Cottrell, 2005). All included participants (n = 10) were Caucasian males, aged 26-53, and are thereby representative of the workforce in this region.

The interviewer (the author) met participants at their worksites and interviews occurred in a location that was removed from construction noise and that ensured privacy. Prior to the actual interview, participants completed an approved informed consent process. Interviews followed a semi-structured format using a consistent interview guide (Figure 25).

Introduction
Thank you for agreeing to be interviewed. Your assistance and comments are valuable to us in our project to improve drywall finishing operations. Our conversation is completely confidential and your comments will in no way be tied to you. Please feel free to talk openly. I will be recording our conversation, for the sole purpose of being able to review it all at a later time. The recording will be kept in strict confidence and not heard by anyone but me. Results of this interview will be combined, anonymously, with those of all the interview I'll be doing, when I

publish the results. As I mentioned on the phone, I'll need for you to review and sign the informed consent form.

Purpose
For my graduate work, I'm investigating the dust generated from drywall sanding operations and am needing to get the opinions of experts in the field. My long-range goal is to improve dust control techniques.

Procedure
This interview will last about 30 minutes. I will be recording it and also taking some notes. There are no right or wrong answers, I am just seeking your opinion as an expert on drywall operations. You may end the interview at any time.

1. Can you tell me about your work as a drywall finisher? How long have you been doing it?
2. What is your opinion of the dust? Is it a problem?
   (probes: do you think it is a health problem? Do you think it is a nuisance? Is it worth controlling?)

3. In your work experience, what types of dust control have you seen used? (probes: why or why not?
4. Have you used a vacuum system? (shows picture)(probe if answer negative: why not?)
5. Have you used wet methods? (shows picture) (probe if answer negative: why not?)
6. Have you used a pole sander? (shows picture) (probe if answer negative: why not?)
7. Have you used respiratory protection? (shows picture) (probe if answer negative: why not?)
8. If you've never used anything to control the dust, why not? (probe if answer negative: why not?)
9. What do you think would motivate you to use something?

Figure 25: Format of Semi-structure Interview.

Interviews lasted from 10 to 44 minutes, with a median of 23 minutes. During the interview, participants were shown photos of the technologies in question, to ensure consistent understanding of what was being discussed. Participants were compensated for their time at a rate of $15 per hour. Interviews were audio recorded and later transcribed verbatim by the author. Transcripts were analyzed using content analysis methods. Codes that were both exhaustive and mutually exclusive were established for the set of open-ended responses, by the researcher. Codes were created that mapped back to the research questions pertaining to constructs of the Health Belief Model. The code definitions are presented below (Table 17). Transcript texts were unitized by the researcher. Text was divided into discrete passages that were unified on a content theme. Units were defined as phrases, sentences, or groups of sentences that were connected in context. Coding units were defined as sentences or groups of sentences connected on a unifying thought. Codes for perceived barriers were grouped by type of control technology. Frequencies of occurrences of codes were the main metric of interest.

Table 17: Code Definitions for Content Analysis

Code	Code Definition
Perceived Threat of Disease (PT)	Comments that pertain to the participant's perceptions of severity or susceptibility of disease associated with drywall dust.
Perceived Benefits of Control (BEN)	Comments that pertain to the participant's perceptions of benefits associated with using dust control technology in question.
Perceived Barriers to Control (BAR)	Comments that pertain to the participant's perceptions of barriers associated with using dust control technology in question
Cues to Action (CA)	Comments that pertain to motivations to adoption of the use of one or more of the technologies.

Results

The content analysis procedures yielded 532 coded units that were further grouped into several subcategories. These are summarized, below, along with representative quotes (Table 18).

Table 18: Sub-categories resulting from content analysis and number of coded units assigned (of a total 532 coded units)

Code	#	Sub-categories
Perceived Threat of Disease (PT)	31	1. Negligible Risk (NR) Comments that indicate that the drywall dust is not a health concern or poses very little risk to personal health. Examples: "Everything causes cancer, or so they say." "It's just a part of the job, I'm not too concerned about it". "Can't be any worse than this cigarette."
	64	2. Perceived Risk (PR) Comments that indicate that the drywall dust is perceived to have

		some risk to the participant's health. Examples: "I know it has silica in it and that isn't good. Who knows, maybe someday it'll be like asbestos and they'll have OSHA all over it" or "I know it's a problem, because I can feel it".
	17	3. Low Personal Susceptibility (LPS) Comments that indicate that participant does not perceive himself to be at risk. Comments such as "I've been at this so long, I figure I'd have been sick by now".
	8	4. High Personal Susceptibility (HPS) Comments that indicate that participant does perceive himself to be at risk. Comments such as "I get home and cough up dust for hours. I know that can't be good." Or "I know a fellow who I used to work with who's got the emphysema now, so I started to wear the masks after I heard that"
Perceived Benefits of Control (BEN)	25	Examples: "It'd be nice to not get into my truck and go home to my family all covered in that dust" or "It's the worst part of the job. Cleaning up that is a total pain in the butt. We should do something" or "It gets in my eyes, makes my throat scratch, I would want to use something to keep it down"
Perceived Barriers to Control (BAR)	82	Ventilated Sander Cost (45) Organizational Barriers (32) Usability Barriers (5)
	56	Pole Doesn't reduce dust (56)
	43	Wet Usability Barriers (43) Example: "Anyone who tells you wet methods work is lying to you!"
	111	Respiratory Protection Usability Barriers (75) Organizational Barriers (36)
Cues to Action (CA)	95	Regulatory (23) Comments pertaining to a lack of regulatory driver. Example: "I bet you if OSHA was to start cracking down on it, we'd see it (controls being adopted)" Organizational (60) Comments pertaining to owners/managers and fellow workers and the patterns of use in that work system. Example: "If they was to buy it and make it mandatory, we'd use it" or "They won't spend on that. That'd cut into the bottom line. We'd use it if they'd buy it" Usability (12) Comments that pertain to the methods perceived usability issues – that if these issues were to be resolved, then use of the methods would improve.

Perceived Threat

The majority of coded comments pertaining to the perception of risk to health associated with the drywall dust did indicate that participants perceive an inherent health risk. More than twice the number of coded comments indicated a perceived risk to health (N=64), than did comments indicate a negligible risk to health (N=31). This finding is of interest, when compared to a recent study of firm owner perceptions that found that just half of the firm owners perceived any risk to worker health and only six percent rated the risk as high (Chapter 2). It would appear from these findings that workers and owners have differing evaluations of the risk to worker health. This finding might be key in understanding why dust controls are used infrequently by drywall finishing firms.

Although the majority of comments indicated that participants perceive a high risk to health, very few comments indicated a personal susceptibility to disease. It would seem, from these comment trends, that workers do understand that mineral dust poses a risk to health, however they do not perceive themselves to be at personal risk of developing negative health outcomes. Therefore, the overall perception of threat associated with the dust is lower, as in the Health Belief Model, perception of threat is a combination of perception of seriousness and perception of susceptibility. This finding might serve to elucidate a causal factor in the low adoption rates of respiratory protection devices by workers.

Barriers

A primary concern of this project was the barriers that exist that prevent the use of various dust control technologies. Workers identified several barriers, for each technology type. The ventilated sander, which has been found in other studies to be the most effective dust control technology of the group studied here (Chapter 3), was not used by any of the participants interviewed. All were familiar with the technology, with one having seen it in use. The one who had seen this technology in use mentioned that it seemed to increase productivity, in that the worker was able to cover more area in a shorter period of time. The majority of comments described barriers associated with organizational factors or cost of the equipment. Many comments pertained to the participants' perception that the owners of the firms would not expend the resources on this type of equipment. Several of the comments indicated that owners passed the burden of control on to the workers. This finding is in agreement with a similar finding of a recent study of firm owner perceptions (Chapter 2). In that study, firm owners indicated that they believed it was the workers' responsibility to protect themselves. A few of the comments in the current study indicated that the participants perceived there to be usability barriers associated with the ventilated sander equipment. Some mentioned that it would be too difficult to maneuver or to use on new construction sites, due to the lack of a power source. These findings are in agreement with previous studies of firm owner perceptions and a laboratory-based usability study (Chapter 2).

For both the pole sander and the wet methods, participants overwhelmingly indicated that these methods would not be acceptable means of dust reduction. The participants all stated that they had used pole sanders in their work, but that they did not believe that pole sanders would effectively reduce the dust. Many mentioned that they have experienced being "covered with dust" following the use of a pole sander. A recent laboratory study did find that the pole sander produced less breathing-zone dust than did the regular block sanding tool. However, it did not eliminate the dust from the work environment (Chapter 3). The participants in this study expressed familiarity with the wet method of sanding, but only one third stated that they had tried this method. All comments pertaining to this method stated that it was not a practical means of performing drywall sanding. The Association of the Wall and Ceiling Industries, however, recommends this method in its technical publication, "Guide for the Finishing of Gypsum Board" (AWCI, 1995). And, a recent laboratory study did find that this method produces less dust than does the standard dry block method (Chapter 3). However, this finding is in agreement with findings of a recent survey of firm owner opinions on the wet method, in which they stated its impracticality (Chapter 2).

Respiratory protection equipment was available to all participants interviewed in this study. All reported having used the technology at some point in their drywall work. Barriers to its consistent use were mostly related to the usability of the technology. Most comments pertained to comfort factors associated with prolonged use of respiratory protection. Many comments indicated that the equipment made breathing more difficult. Many reported that too much moisture accumulates inside the respirator. Several comments indicated that the masks don't seem to function properly. For example, participants noted a sensation of dust in their mouths or a visible deposition of dust on their faces, once the masks were removed. Some of the comments noted the discomfort of the masks pressing against the skin of the face.

Factors associated with interpersonal or organizational barriers were noted in the comments pertaining to the barriers associated with the use of respiratory protection equipment. Some indicated that managers/owners did not encourage their use or that co-workers actively discouraged their use, through negative comments directed at those using them.

Cues to Action

In response to the question about what factors might motivate increased use of dust control technologies, a majority of the response comments were concerned with organizational factors. Primarily, the participants indicated that owners/managers needed to take responsibility for acquiring and implementing dust control technologies. Some comments indicated that increase regulatory drivers would increase implementation of dust control in this industry. Several comments were made about the Occupational Safety and Health Administration (OSHA) that indicated a belief that firm owners respond to a fear of regulatory oversight.

Discussion

The present work is part of a larger effort to identify barriers inherent to the drywall finishing work system that are preventing the use of available dust control technologies. In this larger project, each subsystem of the work system is evaluated to identify key causal factors. In this study, the personnel subsystem was evaluated through in-depth personal interviews of workers in the drywall finishing trade, with the objective of identifying barriers to technology adoption. The results of this study were used, along with findings of studies of the organizational subsystem and technological subsystem, in a macroergonomics evaluation of the drywall finishing work system. Recommendations were made to improve dust control in the industry, as a result (Chapter 5).

The findings of this study concerning the constructs of the Health Belief Model are depicted graphically in a modified version of the model, specific to this occupational health problem (Figure 26.).

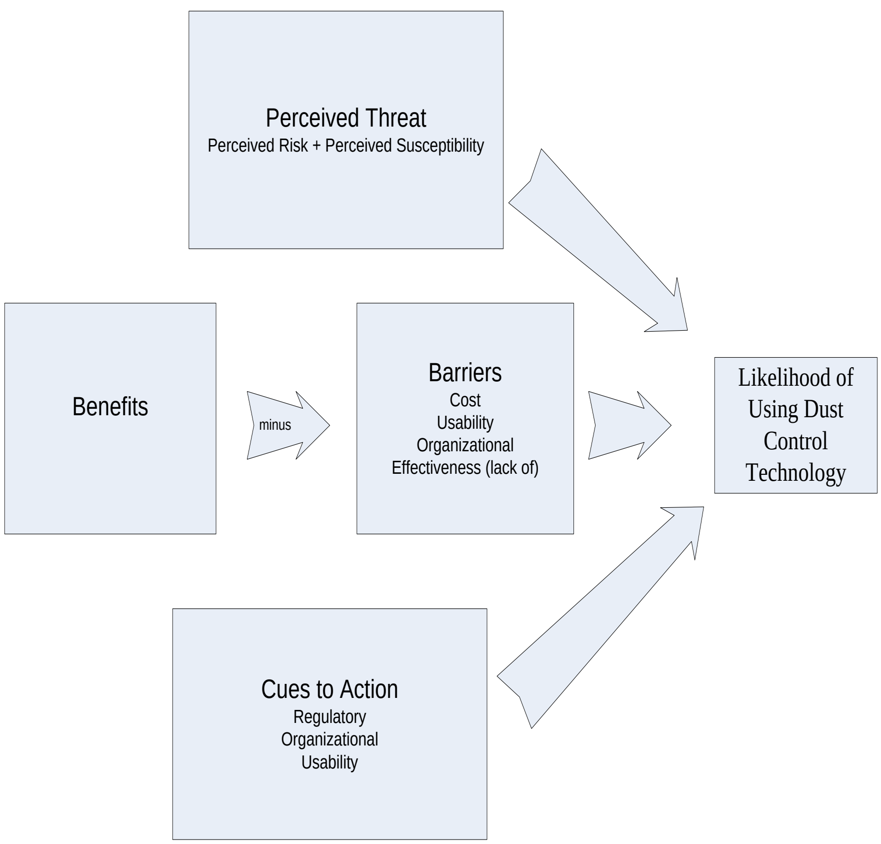

Figure 26: Health Belief Model to Describe Drywall Dust Control (adapted from Rosenstock, 1960)

The present study found that workers had a high perception of the risk associated with the dust, but a low perception of individual susceptibility to respiratory disease. These findings were consistent with those of an earlier study on worker perception of risk and the use of hearing protection devices (Arezes and Miguel, 2005). That study found that individual risk perception was an important predictor of safety behavior, but that workers had low estimates of personal susceptibility to hearing loss and that their assessments of objective risk were faulty.

Findings here indicate that few dust controls are currently in use in the subject population. While the drywall finishers did indicate having access to respiratory protection equipment, that technology is seldom used in practice. The low usage rates were attributed, in large part, to usability barriers associated with the personal protective devices.

Participants indicated that other, more effective, dust control technologies are not in use in their work organizations. The main barriers identified to explain this were organizational and cost. Cost barriers were perceived by the participants as the underlying causal factors to explain manager/owner reluctance to make control technologies available. Organizational barriers included issues such as management/worker relations and interpersonal influences. Management/worker relations were inclusive of comments about management support for the use of controls and management willingness to provide access to control technologies. Interpersonal influences included comments about the influence of co-worker opinion and behavior on the interviewee's use of controls technologies. These findings are similar to those of a related study of factors influencing worker use of hearing protection in the agricultural industry (McCullagh, et al., 2002). In that study, it was found that interpersonal influences and perceived barriers were the strongest predictors of use of hearing protection. Similarly, a study employing structural equation modeling of factors associated with factory worker decision to use hearing protection equipment found that benefits of use, barriers to use, and gender were significant predictors of adoption of protective devices (Lusk, et al. 1994).

Limitations

A primary limitation of this study was associated with the narrow set of demographic parameters associated with the participant sample. Since this was a convenience sample of workers from the drywall finishing industry local to Southwest Virginia, the generalizability of the results is limited. However, the results are consistent with many findings of related projects by the authors. An expansion of this project, with a sample that ensures representativeness of the industry-wide demographics, would enhance our understanding of worker perceptions in this field. An additional limitation arises from the qualitative nature of the study, which prevents direct comparison of results to similar studies employing quantitative methods.

Conclusions

Workers perceive a health risk associated with drywall dust; however their individual perceptions of susceptibility to disease are low, which might impact their health behavior outcomes in choosing to protect themselves from the dust on the job. Several key barriers to the use of dust control technology were identified. Organizational and cost barriers were of primary note, mentioned for the ventilated sanders. Pole and wet methods were not perceived to have much practical use in the control of dust or in task accomplishment. Respiratory protection barriers were mainly in the realm of comfort, interpersonal influences, and usability. These identified barriers were used in a further evaluation of the work system and recommendations for improvement were made.

Chapter 5: Macroergonomic Evaluation
Drywall Finishing Operations and Intervention Design

Abstract

Objective:

To perform a macroergonomic evaluation of the drywall finishing work system, using the System Analysis Tool (SAT), with the purpose of developing several intervention alternatives to reduce worker exposure to drywall dust.

Methods:

Findings from three separate studies of the subsystems of the drywall finishing work system were used as inputs into the Systems Analysis Tool (SAT). A Problem Factor Tree (PFT), Objectives/Activities Tree (OAT), and Input-Output Flow Diagram were developed to describe the barriers inherent to the current drywall finishing industry use of dust control technologies.

Results:

Educational, health promotion, tool redesign, and regulatory interventions are proposed as strategies to improve dust control and worker protection in the drywall finishing industry.

Keywords: macroergonomics, drywall, dust, construction work, usability, dust control

Introduction

Respiratory disease among construction workers in general, and plasterers and wall finishers in particular, is a major public health concern. Workers in these trades suffer from disproportionately high rates of respiratory disease and disability (Wang, 1999). Drywall finishing operations have been associated with worker over-exposure to dust that contains known particulate respiratory health hazards, such as silica, talc, and mica (NIOSH, 1997). Despite the existence of engineering and work-practice control technologies for the mitigation of this hazard, worker exposures persist in the construction industry (Carlton *et al.*, 2003).

Three studies (Chapters 2 - 4) were conducted as distinct parts of a collective project concept that employed a macroergonomic framework to evaluate the drywall finishing work system with the intent of designing interventions to improve industry-wide dust control. The main findings of each were employed as inputs in this macroergonomic system analysis.

The macroergonomic approach defines a work system as one in which two or more people work together in interaction with technology within an organizational context (Kleiner, 2006). This definition identifies three key subsystems of any work system: personnel, technological, and organizational. The organizational subsystem can be further described as having internal and external influences: physical, cultural, legal and political. According to the macroergonomic approach, all subsystems should be included in system analysis, design, and improvement (Hendrick, 2001). In the drywall finishing work system, it can therefore be assumed that organizational, human, and technological factors are important considerations when planning work designs to improve worker health. Therefore, all three subsystems were evaluated for potential barriers to the control of dust in drywall finishing operations (Figure 27). To perform the macroergonomic evaluation, three studies were designed to solicit information about barriers inherent to each of the major subsystems. Information regarding these identified barriers is them employed in the System Analysis Tool (SAT), to develop recommended alternatives for system improvement

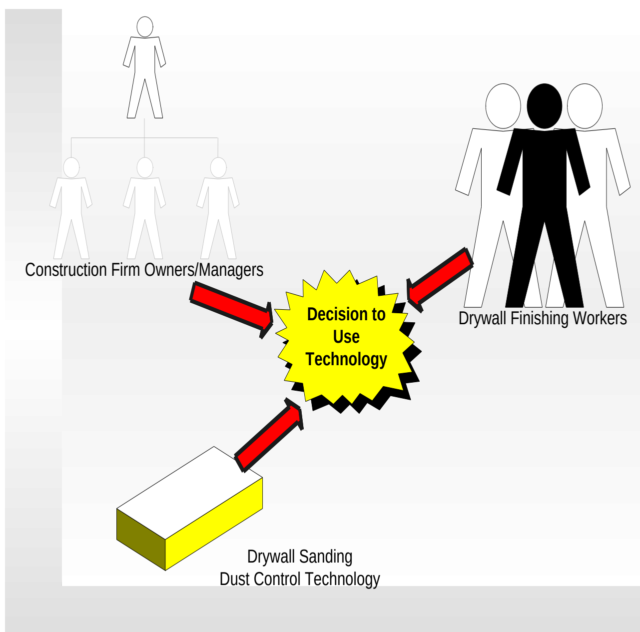

Figure 27: Subsystems of Drywall Finishing Work System

Study 1.

An evaluation of the organizational subsystem was performed in this study of drywall finishing firm owner perspectives. A telephone survey was administered to a target sample 1000 drywall-finishing contractor firms listed in the two major trade organizations in that field. This survey was constructed to measure the frequency of use of four primary and contemporary dust control technologies and respiratory protection. For each technology, firms were asked about barriers to implementation.

Study 2

In this study, problems inherent to the technological subsystem, especially the technology-user interface was examined. In a laboratory setting, participants performed simulated drywall finishing tasks using each of the four most common methods: plain sanding block, pole sander, wet method, and vacuum sander. Resulting dust concentrations and usability metrics were the outcomes of interest. Barriers to use associated with usability metrics were identified.

Study 3

The personnel subsystem was evaluated in the third study of worker perspectives on drywall dust control technologies. Drywall finishing worker attitudes toward the four technologies were explored through in-depth personal interviews. Attitudes and perceptions toward the technologies were solicited, and emergent themes were explored. Workers described perceived barriers to the adoption of the various dust control technologies.

Methods

Systems Analysis Tool (SAT)

The Systems Analysis Tool (SAT) is the macroergonomics work system assessment methodology employed in this study. The SAT has roots in systems engineering theory (Hall, 1969) and a system analysis framework for policy decision making (Mosard, 1982). It is restated as a formal tool in the Handbook of Human Factors and Ergonomics Methods (Stanton *et al*, 2005). This tool consists of a seven step process for identifying work system problems and causal factors and developing strategic solutions:

1. Define the problem: create a problem factor tree (PFT)
2. Develop an objectives/activities tree (OAT)
3. Model alternatives: the input-output flow diagram (IOFD)
4. Evaluate alternatives: evaluation scorecard table (EST)
5. Select an alternative: decision criteria table (DCT)
6. Plan for implementation: scheduling and management of project flow
7. Evaluation, feedback, and modification process

The current research employs the first three steps of this process to analyze the diverse problem factors associated with the drywall finishing industry low usage of dust control measures and then to develop several intervention alternatives.

1. Problem Factor Tree (PFT)

From the system performance data collected in previous work by the authors, the problem factor tree (Figure 28) was constructed to assess problems and causal factors of the breakdown in use of drywall sanding operations dust control technologies. This tool incorporated inputs from the three main subsystems of the drywall finishing industry: organizational, technological and personnel. Additionally, external environmental and interface factors were included in the analysis .

The problem under consideration is the fact that dust control technologies are not being used during drywall finishing operations. Root causal factors contributing to this problem were identified as arising from the technology, the interface between the technology and the human users, the work environment, the organizational system, the worker system, and the external environment and are shown across the base of the PFT diagram. Studies of each of these subsystems found the main themes identified and are shown as problem factors in the body of the PFT. These are the main problem elements, constraints, and barriers that contribute to the sub-problem elements: tendency to choose sub-optimal sanding technology, reliance on personal protective equipment as a means of control, failure to use respiratory protection when it is provided, failure of the workers and managers to accurately assess the risk to human health associated with drywall dust, and failure of the workers and managers to accurately assess the benefits that would be derived from the use of dust control technologies.

The ventilated sander and the low-dust joint compound are the two dust control technologies recommended by the authors of this study. This decision is based upon the laboratory study findings, which indicated that the ventilated sander offers the greatest degree of worker protection, as compared to the dry block sander, the wet methods and the pole sander. The survey of firm owners and interviews of workers, which indicated significant barriers to the use of wet methods and the results of the firm owner survey, which indicated a high degree of interest in using the low-dust joint compound, are also key factors in the selection of these technologies. And, lastly, important were the results of the usability study, in which the ventilated sander performed well overall.

With that objective in mind, the following table (Table 19) summarizes the barriers that have been identified that stand in the way of industry-wide adoption of either of these technologies. These barriers are then used in the subsequent steps of the SAT evaluation.

Table 19: Barriers to Adopting Technologies, as Identified in Studies of the Organizational, Technological, and Personnel Subsystems of the Drywall Finishing Work System

	Ventilated Sander	Low-dust Compound
Organizational	Cost Usability Environmental Factors Productivity	Cost Availability Effectiveness
Technological	Usability Perceived Comfort	n/a
Personnel	Cost Organizational Factors Environmental Factors	Cost Effectiveness

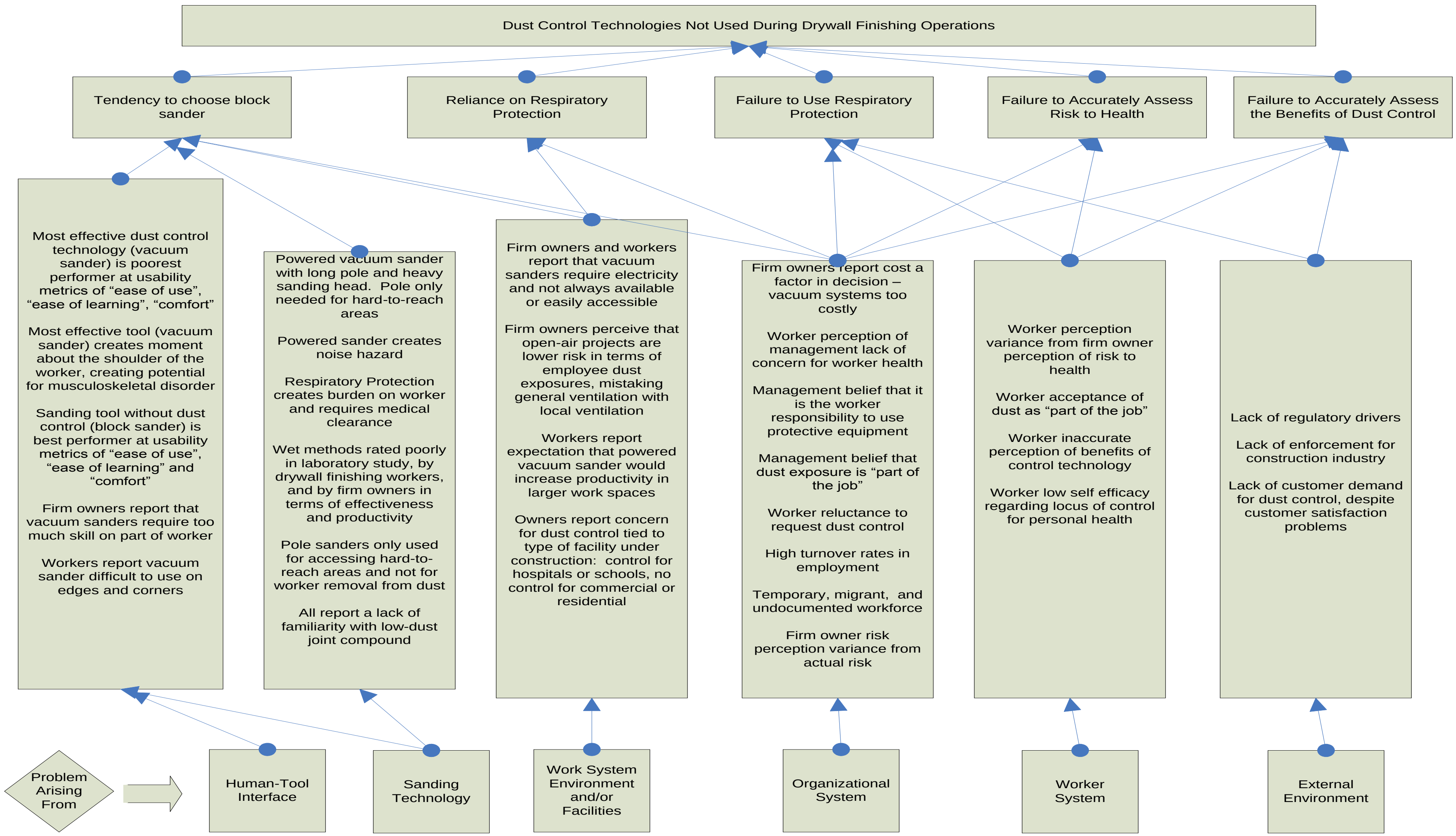

Figure 28: Problem Factor Tree

2. Objectives/Activities Tree (OAT)

The second step in the SAT is to set objectives and develop evaluation criteria (Figure 29). This is accomplished by identifying major needs, goals, objectives and sub-objectives associated with the identified problem. For the problem at hand, the major goal is a reduction of worker dust exposure in the drywall finishing industry. One objective would be an increased use of ventilated sanders and low-dust joint compound, as these are the methods have emerged from these combined project as the optimal solutions, based on firm owner, worker, and usability study outcomes. A second objective would be a diminished reliance on respiratory protection as a means of protecting workers. Intermediary objectives that would need to be addressed in order to achieve the goal would include changes to tool design to address usability issues, a change in worker perception of risk and susceptibility and a change in firm owner perception of locus of responsibility for dust control: shifting the burden from the worker to the owner.

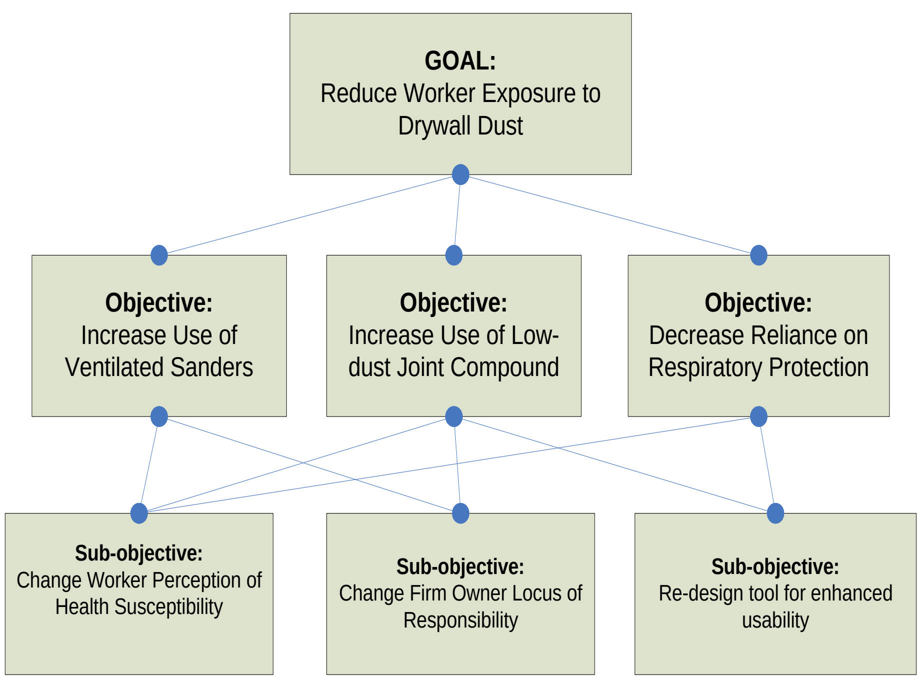

Figure 29: Objectives/Activities Tree (OAT)

3. Modeling Alternatives: Input-Output Flow Diagram

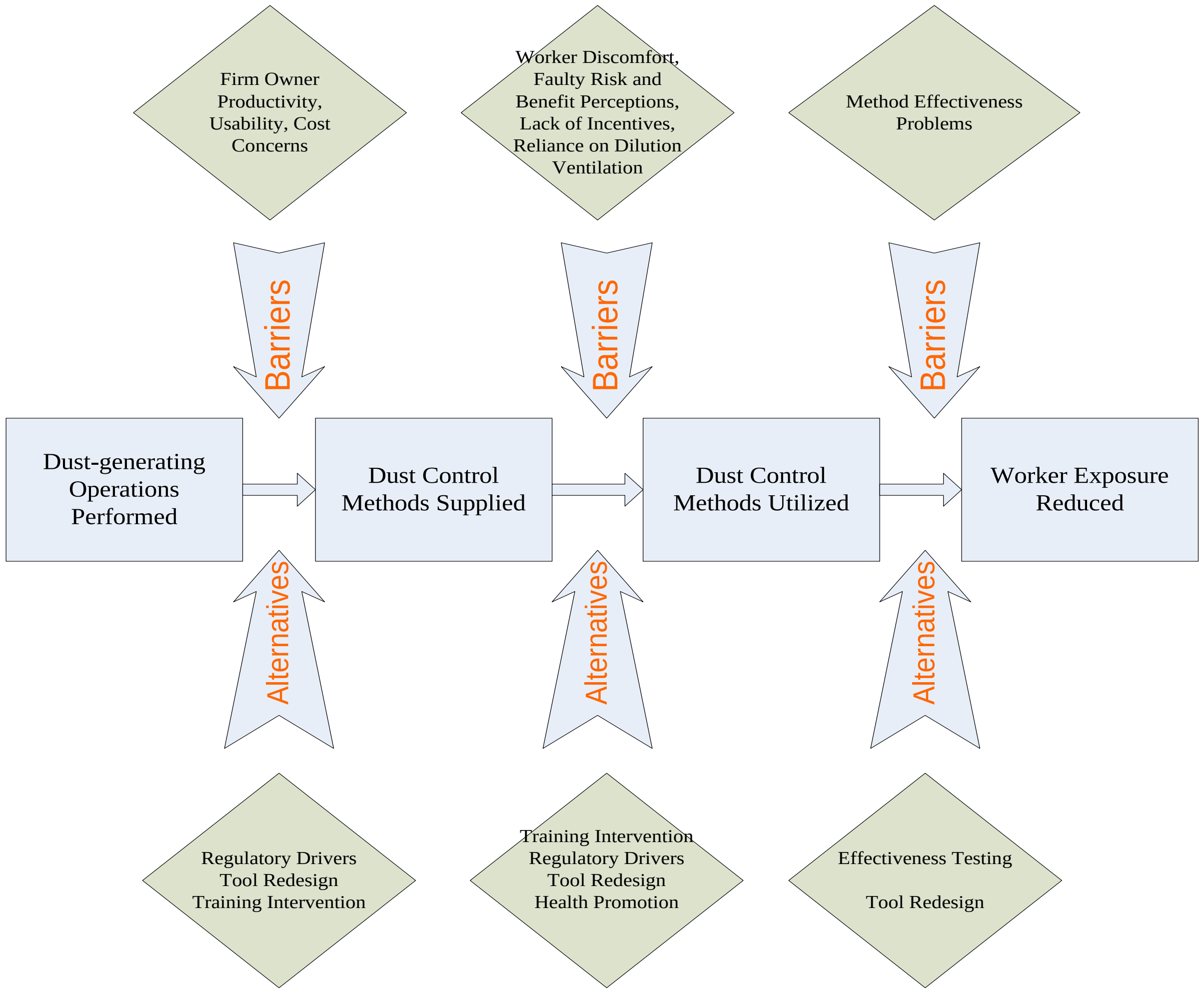

Figure 30: Input-Output Flow Diagram

4. Recommended Alternative Solutions

Increase Regulatory Drivers

An increase in regulatory oversight of the industry would provide incentive to the firm owners to ensure that dust concentrations do not exceed permissible exposure limits for silica. An absence of this sort of incentive or driver was noted in both the studies of firm owner perceptions (Chapter 2) and drywall worker perceptions (Chapter 4). Firm owners indicated this absence of incentive when discussing their barriers associated with the low-dust joint compound. Several comments were made that it would not make sound business sense to adopt the use of a joint compound that was more costly than the current products used. In the interviews with workers, many comments were made about regulatory drivers, when the participants were asked about cues to action. A theme emerged that indicated that it is the belief of the workers that construction firm owners are motivated by a fear of regulatory consequences.

The Occupational Safety and Health Administration (OSHA) does have some current standards concerning some of the primary constituents of drywall joint compound. In its standards for the construction industry (29 CFR 1926.55), it has adopted the "Threshold Limit Values of Airborne Contaminants for 1970", a list of occupational exposure limits published by the American Conference of Governmental Industrial Hygienists. This list includes exposure limits for crystalline quartz (silica), talc, and mica. The standard states that exposure to employees above these specified limits shall be avoided. It also states that compliance is to be achieved through the use of administrative or engineering controls as a first option, whenever feasible. It then states that the use of personal protective equipment is allowed when these other control types are not feasible.

While this regulation does exist to control worker exposure to these hazards, enforcement of it is not commonplace. According to a summary report by Roznowski (2000), for the period 1985 to 1996, there were only 128 health inspections of silica exposure in the construction industry. Of these, the majority (53) were undertaken because of a referral from the National Institute for Occupational Safety and Health. A large proportion (43) was initiated via employee complaint. Eighteen of the inspections were follow-up, and only 14 were planned. This indicates that inspections of this nature, for this hazard and in this industry, have been a low priority for OSHA in the past. This same report indicated that 22% of the samples taken by OSHA for silica exposure in the drywall trades of the construction industry, during that same time period, exceeded the occupational exposure limits. Roznowski also notes in this report that, for the given period of time, 11% of the deaths due to silicosis in the United States were workers of this trade group.

Based on these reports and the findings of studies of firm owner perceptions of barriers and worker perceptions of cues to action, it is the recommendation of the author that regulatory oversight of this hazard be increased in the future. This could add a significant cue to action to adopt effective controls for both the owners and the workers of this industry.

Tool Redesign

It is recommended that the ventilated sander be subjected to iterative re-design procedures, factoring in usability testing and biomechanics analysis, to address some of the key findings of this research. Notably, adjustability in the length of existence of a pole on the sanding head, and the weight and vibration associated with the device. Also key is the ability to operate in both large- and small-scale work settings and in settings without a power supply. Following is a set of design heuristics (Table 20) that emerged from the laboratory study of the usability of this technology.

Table 20: Design Guidelines for Powered Ventilated Drywall Sander

Usability Construct	Study Findings	Design Recommendations
Ease of Use	Awkward	Make pole removable or adjustable in length
	Rotation of sanding head created problems with maneuverability	Oscillating sanding surface
	Long pole made it difficult to sand at head-height, or below	Add adjustability to pole length; Removable pole to be used only when needed
	Could not see work area	Sanding unit as a hand-held device; add adjustability to pole length; Removable pole to be used only when needed
	Could not maneuver in small spaces	Sanding unit as a hand-held device; add adjustability to pole length; Removable pole to be used only when needed
	Cord/vacuum hose got in way	Coiled, retractable hose
Perceived Comfort	Too heavy	Sanding unit as a hand-held device; add adjustability to pole length; Removable pole to be used only when needed; Use of light—weight polymeric materials; reduce size of sanding head
	Fatigued arms, shoulders, chest	Sanding unit as a hand-held device; add adjustability to pole length; Removable pole to be used only when needed; Use of light—weight polymeric materials; reduce size of sanding head
	Difficult to grip	Change diameter of pole to accommodate twenty-fifth percentile male anthropometry
	Difficult to change hand position	Add adjustability to pole length; Removable pole to be used only when needed; Change position of controls on pole to allow for movement of hands along pole
	Loud	Dampen vibration in sanding head; use polymeric materials; muffle vacuum

Educational Interventions

Many of the barriers identified in the three studies are amenable to health promotion interventions strategies. In the organizational subsystem, health promotion and educational interventions are recommended to target barriers associated with firm owner perception of the risk associated with the dust, the current expectation that protection is the responsibility of the worker, and the misconceptions related to what constitutes and effective control. In the technological subsystem, educational interventions designed to communicate the relative effectiveness of the different available control technologies and the proper use of the ventilated sander, would address some of the identified barriers concerning ease of learning and productivity. In the personnel subsystem, health promotion and education interventions are recommended to target organizational barriers, particularly associated with interpersonal influences. Also in this subsystem, health promotion to alter the worker perception of susceptibility to respiratory disease is likely to improve employee health behaviors and the use of respiratory protection.

Several studies have demonstrated the usefulness of health promotion interventions in occupational contexts. Kerr, et al. (2002) applied the Health Promotion Model to improve Mexican garment factory worker use of hearing protective devices. That project identified perceived benefits and barriers to technology adoption and developed recommended intervention strategies to improve the use of hearing protection. In a study of hearing protection device use in Portugal, Arezes and Miguel (2005) found that risk perception was a major predictor of worker health behavior in this occupational context and targeted educational programs at addressing a shift in risk perception. A study of pesticide safety practices among farm pesticide applicators also applied a health promotion model to the design of an intervention. In this case, self-efficacy and interpersonal factors were the targeted constructs in the intervention.

These studies indicate that health promotion models and associated interventions have relevance to the problems in the occupational health realm. In the present research, the issue of adoption of protective technology is at issue. This is directly analogous to the aforementioned studies of worker adoption of protective devices. Future research into the development and evaluation of an intervention to improve worker protection in the drywall industry is recommended.

Conclusions

Technologies exist to effectively reduce worker exposure to known and regulated health hazards associated with drywall finishing operations, however usage rates are low across the industry. Barriers to the adoption of protective controls exist in the organizational, technological, and personnel subsystem, as well as the interfaces among them. The Systems Analysis Tool was employed to analyze the results of previous scans of the work system and develop three alternatives for system improvement. Future research is recommended to select, implement and evaluate one or more of the recommended alternative interventions.

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Appendix A: Institutional Review Board Documentation

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project: Evaluation of Dust Control Technologies for Drywall Finishing Operations: Industry Implementation Trends, Worker Perceptions, Effectiveness and Usability **(Study 3)**
Investigator(s) Maury Nussbaum, PhD and Deborah Young, doctoral candidate

I. Purpose of this Research/Project
Respiratory disease among construction workers in general, and plasterers and wall finishers in particular, is a major public health concern. Workers in these trades suffer from disproportionately high rates of respiratory disease and disability. Drywall finishing operations have been associated with worker over-exposure to dust that contains known particulate respiratory health hazards, such as silica, talc, and mica (NIOSH, 1997). Despite the existence of engineering, work-practice, and personal-protective-equipment (PPE) control technologies for the mitigation of this hazard, worker exposures persist in the residential construction industry (Carlton *et al.*, 2003).

There are important gaps in the existing knowledge regarding this occupational health problem. A search of the literature revealed no empirical evaluation of construction industry usage trends for the various available technologies. Aside from a pilot project conducted by the National Institutes for Occupational Safety and Health, there has been no thorough evaluation of the effectiveness of the different dust control technologies (NIOSH, 2000). Additionally, investigation is needed to identify the causes of substandard controls usage. Once probable causes are identified, intervention strategies can be developed and deployed in order to improve controls usage rates in drywall finishing operations. The proposed research aims to address these gaps.

II. Procedures
You will meet with the investigator one-on-one. In that meeting, you will be given a brief introduction to the purpose and procedure of the study and the in-depth interview will proceed. The interviewer will take notes and also will audio-record the interview for later transcription.

III. Risks
Risks are minimal to you. Personal, identifying information will not be collected. Audio recordings will only be used by the researcher. The content of what is said in the interview will not be released in any format that will be connected with you.
IV. Benefits
The long-range goal of the study is to improve dust control in drywall sanding operations and to improve the technologies.

V. Extent of Anonymity and Confidentiality

This interview data will be anonymous. You will not be identified and, therefore, your identity will never be associated with this interview data.

VI. Compensation
You will be compensated at a rate of $10 per hour.

VII. Freedom to Withdraw
Subjects are free to withdraw from a study at any time without penalty. If they choose to withdraw, they will be compensated for the portion of the time of the study. Subjects are free not to answer any questions or respond to experimental situations that they choose without penalty. There may be circumstances under which the investigator may determine that a subject should not continue as a subject. The subject must be compensated for the portion of the project completed.

VIII. Subject's Responsibilities
I voluntarily agree to participate in this study. I have the following responsibilities:
To participate in an interview in which I share my opinions about dust control.

IX. Subject's Permission
I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date__________
Subject signature
____ Date __________
Witness (Optional except for certain classes of subjects)

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whomto contact in the event of a research-related injury to the subject, I may contact:

Chair, Virginia Tech Institutional Review
Board for the Protection of Human Subjects
Office of Research Compliance
1880 Pratt Drive, Suite 2006 (0497)
Blacksburg, VA 24061
______________________________________ ________________________
Investigator(s) Telephone/e-mail
____ ________________________
Faculty Advisor Telephone/e-mail
____ ________________________

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project: Evaluation of Dust Control Technologies for Drywall Finishing Operations: Industry Implementation Trends, Worker Perceptions, Effectiveness and Usability (Study 2)

Investigator(s) Maury Nussbaum, PhD and Deborah Young, doctoral candidate

I. Purpose of this Research/Project

Respiratory disease among construction workers in general, and plasterers and wall finishers in particular, is a major public health concern. Workers in these trades suffer from disproportionately high rates of respiratory disease and disability. Drywall finishing operations have been associated with worker over-exposure to dust that contains known particulate respiratory health hazards, such as silica, talc, and mica (NIOSH, 1997). Despite the existence of engineering, work-practice, and personal-protective-equipment (PPE) control technologies for the mitigation of this hazard, worker exposures persist in the residential construction industry (Carlton *et al.*, 2003).

There are important gaps in the existing knowledge regarding this occupational health problem. A search of the literature revealed no empirical evaluation of construction industry usage trends for the various available technologies. Aside from a pilot project conducted by the National Institutes for Occupational Safety and Health, there has been no thorough evaluation of the effectiveness of the different dust control technologies (NIOSH, 2000). Additionally, investigation is needed to identify the causes of substandard controls usage. Once probable causes are identified, intervention strategies can be developed and deployed in order to improve controls usage rates in drywall finishing operations. The proposed research aims to address these gaps.

II. Procedures

You will be given a brief training on how to sand drywall mud and then will be given instruction on how to wear respiratory protection equipment. There will be four sanding sessions, each lasting 15 minutes. You will enter the ventilated sanding area and will sand the drywall mud for 15 minutes. Afterward, you will be asked to complete a questionnaire, before beginning the next sanding session. After the four sanding sessions, you will be asked to complete a different questionnaire.

III. Risks

Risks are minimal to you. Personal, identifying information will not be collected. Dust exposure during the sanding sessions will be brief and will be controlled by the use of respiratory protection.

IV. Benefits

The long-range goal of the study is to improve dust control in drywall sanding operations and to improve the technologies.

V. Extent of Anonymity and Confidentiality

This data will be anonymous. You will not be identified and, therefore, your identity will never be associated with this interview data.

VI. Compensation
You will be compensated at a rate of $10 per hour. The experiment should take from one to two hours.

VII. Freedom to Withdraw
Subjects are free to withdraw from a study at any time without penalty. If they choose to withdraw, they will be compensated for the portion of the time of the study. Subjects are free not to answer any questions or respond to experimental situations that they choose without penalty. There may be circumstances under which the investigator may determine that a subject should not continue as a subject. The subject must be compensated for the portion of the project completed.

VIII. Subject's Responsibilities
I voluntarily agree to participate in this study. I have the following responsibilities:
To participate in a lab study involving four sanding sessions, sanding drywall joint compound. To complete user-reaction questionnaires after each sanding session.

IX. Subject's Permission
I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:
____ Date__________
Subject signature
____ Date __________
Witness (Optional except for certain classes of subjects)

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury to the subject, I may contact:

Chair, Virginia Tech Institutional Review
Board for the Protection of Human Subjects
Office of Research Compliance
1880 Pratt Drive, Suite 2006 (0497)
Blacksburg, VA 24061

_______________________________________ ________________________
Investigator(s) Telephone/e-mail
_______________________________________ ________________________
Faculty Advisor Telephone/e-mail
_______________________________________ ________________________

Appendix B: Study 1 Survey Instrument

CALLING INFORMATION: Known Respondent Firm Original Phone Number

Hello, my name is ________ and I'm calling from the Virginia Tech Center for Survey Research regarding practices your firm may use to control dust while working on drywall projects. This brief survey will be used to improve drywall dust control technologies for the industry. Your responses are completely confidential and will never be linked to your firm in any way.

May I speak with the person in your organization who is most knowledgeable about drywall projects?

I will try calling him/her back at: ____

Q1: How would you rate the negative impact of drywall dust on your firm's productivity? Would you say that it has had a great impact, some impact, not much of an impact, or no impact?

Q2: How would you rate the negative impact of drywall dust on customer satisfaction? Would you say that it has had a great impact, some impact, not much of an impact, or no impact?

Q3: Would you say that drywall dust poses a great threat, somewhat of a threat, not much of a threat, or no threat to the health of the workers in your firm?
If NOT MUCH OR NO – Are dust control technologies being used that are helping?

Q4: Does your firm use wet methods when sanding drywall compound always, often, sometimes, rarely, never?
    If no, why not?

Q5: Does your firm use respiratory protection such as respirators or masks when workers are sanding drywall compound always, often, sometimes, rarely, never?
If no, why not?

Q6: Does your firm use pole sanders when sanding drywall compound always, often, sometimes, rarely, never?
If no, why not?

Q7: Does your firm use ventilated or vacuum sanders as a means of controlling dust when sanding drywall compound always, often, sometimes, rarely, never?
    If no, why not?

Q8: Does your firm use a low-dust drywall compound or setting compound to reduce dust levels always, often, sometimes, rarely, or never?

If no, why not?

Q9: Does your firm use any other methods of controlling dust generation?

Q10: How many employees does your firm have?
Q11: Are your employees affiliated with a union?
Q12: Does your firm hire subcontractors to perform drywall finishing always, often, sometimes, rarely, or never?

Q13: Is there anything else you can tell us about your experience with drywall dust or drywall dust control technologies?

Appendix C: In-depth Interview Guide

Participant ID: ______________________

Date: __________________

Introduction
Thank you for agreeing to be interviewed. Your assistance and comments are valuable to us in our project to improve drywall finishing operations. Our conversation is completely confidential and your comments will in no way be tied to you. Please feel free to talk openly. I will be recording our conversation, for the sole purpose of being able to review it all at a later time. The recording will be kept in strict confidence and not heard by anyone but me. Results of this interview will be combined, anonymously, with those of all the interview I'll be doing, when I publish the results. As I mentioned on the phone, I'll need for you to review and sign the informed consent form.

Purpose
For my graduate work, I'm investigating the dust generated from drywall sanding operations and am needing to get the opinions of experts in the field. My long-range goal is to improve dust control techniques.

Procedure
This interview will last about 30 minutes. I will be recording it and also taking some notes. There are no right or wrong answers, I am just seeking your opinion as an expert on drywall operations. You may end the interview at any time.

1. Can you tell me about your work as a drywall finisher? How long have you been doing it?
2. What is your opinion of the dust? Is it a problem?
    a. (probes: do you think it is a health problem? Do you think it is a nuisance? Is it worth controlling?)

3. In your work experience, what types of dust control have you seen used? (probes: why or why not?
4. Have you used a vacuum system? (probe if answer negative: why not?)
5. Have you used wet methods? (probe if answer negative: why not?)
6. Have you used a pole sander? (probe if answer negative: why not?)
7. Have you used respiratory protection? (probe if answer negative: why not?)
8. If you've never used anything to control the dust, why not? (probe if answer negative: why not?)
9. What do you think would motivate you to use something?

Appendix D: Usability Evaluation Instrument – Individual Technology

Technology Type: __________

Participant Code: ______________

Please indicate your opinions of the following, using the scale provided:

Ease of Learning					
I felt this was easy to learn.	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
It did not take long for me to feel like I was using it correctly	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
Anyone could learn to use this quickly	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
Ease of Use					
I felt like it was easy to use this to do the sanding	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
I did **not** feel frustrated while using this technology	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
I would choose to use this sanding technology, if I had to peform this task in real life	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
I didn't have any problems while using it	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
Productivity					

I felt like I could get the sanding done quickly with this technology	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
I felt like I could get the sanding done correctly while using this technology	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
Comfort					
I felt comfortable while using this technology	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
I felt I had to apply a lot of force to accomplish the sanding task	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐
My hand/arm felt comfortable during this task	Strongly Disagree ☐	Disagree ☐	Neutral ☐	Agree ☐	Strongly Agree ☐

Additional Comments:

Appendix E: Usability Evaluation Instrument – Technologies Comparison

Please use the following rating scale to rank your preferences regarding the sanding technologies used in this study:

1 = Best
2 = Second Best
3 = Third Best
4 = Worst

A. Please rate in terms of **easiest to learn** to use:

___ Sanding block

___ Pole Sander

___ Wet Method

___ Vacuum Sander

B. Please rate in terms of **easiest to use** to perform the task:

___ Sanding block

___ Pole Sander

___ Wet Method

___ Vacuum Sander

C. Please rate in terms preference **overall** :

___ Sanding block

___ Pole Sander

___ Wet Method

___ Vacuum Sander

D. For **Overall** BEST: Why was this your choice?

E. For **Overall** WORST: Why was this your choice?

Appendix F: Study 1 Responses to Open-Ended Questions

Q3. Are dust control technologies being used that are helping?

Respondent #	***Response***
261	New masks fitted once a year.
59	Broom.
75	Yes.
55	We use vacuum sanders and dust masks.
56	Vacuum sanders.
264	Use a new taping compound by USG.
74	Yes.
263	Dustless vacuum for tapers and we use 3M dust masks.
73	No.
57	Respirators and safety glasses.
48	Use dust protection methods (like respirators).
65	Relies on dust masks.
40	Yes, we use respirators.
258	Respirators.
267	We use respirators.
22	Yes, we use dust masks, etc.
21	Yes, depends on the job we use vacuum sanders and masks.
38	Yes, respiratory protection.
37	We dust barriers.
14	Yes, use dust masks when sanding.
17	We use dust masks.
35	Wear respiratory protection or dust masks.
61	No comment.
79	Yes gypsum low duct taping product.
85	Seals work areas with Visqueen (polyvinyl barriers).
71	No more asbestos in drywall.
63	Few occasions, hospital or nursing homes take more measures.
10	New drywall mud (dust-free). Vacuum sanders. Upgraded masks.
266	They wear masks.
29	Dust masks and respirators.
82	Yes, wear masks and safety glasses.
62	Face masks, hats and taping areas off.
28	Using protection like masks.
19	Not really.
257	Vacuum sanders.
20	We do dustless sanding.
262	Masks.
2	Masks, vacuum filters, heppa filters.
27	Yes, we use dust masks, and electric vacuum cleaners.
15	Not really, just what is in the mud and vacuum sanding.

44	OSHA masks, respirators and negative air systems.
52	Does use various control technologies, like respirators.
250	Dust masks and vacuum sanders.

Q3. Continued

89	Use masks.
107	Particle masks required on jobs.
251	Masks, air filtration system, low dust products, and vacuums.
124	Masks and plastic barricades.
230	Dust masks and vacuum sanders.
226	Masks and protected sanders.
225	Dust masks, respirators, Visqueen barriers.
126	Negative air. Vacuum sanders.
130	Use respirators, and dust collectors.
224	Filtered air
223	Dust masks.
108	Use masks.
222	Masks.
94	Dust masks, negative air rooms, vacuum sanders.
131	The dust masks and filters are being improved.
231	We use ventilation, vacuum sanders.
221	Respirators, air movers (ventilation).
215	We wet it down when needed.
213	Yes.
211	Use proper protections; follow OSHA standards.
204	No.
203	Vacuum sanders.
236	We use masks and sanding vacuums.
170	Dustless sanders, masks.
199	Use face mask.
196	Fresh air ventilation (although it mainly just moves the particulate around the site); mister (airborne water) systems to weigh down the dust and remove it from circulation; respirators and masks; absorbent materials to take the airborne particulates out of circulation.
195	No.
192	Use dustless sanders.
97	Rarely use dust control methods.
189	Wear masks and put up barriers.
235	Wear dust masks.
166	Routinely use respirators and masks.
110	Not a problem on our worksites.
185	Masks.
168	Masks, Plus3 from USG to help dust settle. Plus3 is a USG compound that creates larger dust particles that settle to the ground better (less airborne dust).
137	Use respirators and goggles.

184	Workers use masks.
101	Nothing specific.
136	Nothing specific.

Q3. Continued

122	Vacuum sanders.
183	Visqueen barriers.
102	Protective gear.
145	Nothing specific.
243	Use masks.
181	Masks.
182	Respirators.
165	USG has a good product.
245	Use vacuum sanders.
237	Vacuums, daily clean-ups.
177	Wear masks.
148	Different types.
252	Vacuum dust floor sweep on the floors to keep dust down.
118	Vacuum sanders.
174	Yes.
173	With most people dust is not a problem. We use HEPA filters.
171	Masks and respirators. Sanding vacuums.
149	No.
123	Use dustless sanders. Use USG, dust falls to the ground.
247	"Down with dust" from USG - product drops the dust to the floor.
134	Masks.
121	Dust masks.
132	Wear masks.
164	Dust masks.
111	Filtering masks.
140	Wear dust masks.
152	Sanding vacuum.
154	Masks.
241	Performs air control safety checks with 4 hour work window.
151	Masks.
117	We use dust masks and water based products, no threat.
113	We use masks, respirators, vacuum sanders and tenting off areas.
112	Uses dustless methods.
156	Masks and barriers.
158	Certified dust masks.
240	A new product by USG with a low dust factor.

Q4. Does your firm use wet methods when sanding drywall compound always, often, sometimes, rarely, or never? Responses to “rarely” and “never” provided.

Respondent #	***Response***
72	Use other methods.
79	Good quality job.
112	Since we use dustless sanders, don't need wet methods.
81	Not compatible in quality.
96	Messy. Workers don't like this method.
111	Too slow, no need to use.
85	Generally time-consuming and costly.
115	No reason.
66	Company does not sand they only install.
73	Not cost effective.
65	Very slow and labor-intensive.
106	We are a Union shop just don't do it.
117	Use sandpaper does quicker & nicer job, use dustless sanders.
71	Raising the "nap" on the paper and takes longer to do an area.
103	Quality of finish.
118	Not as good of a finish on the product.
104	New construction so it is not a problem.
258	We have better methods we use.
102	Not familiar with them.
253	Not pleased with result.
250	Don't work.
230	Never done it; not our practice.
83	Not cost-effective.
99	Tapers used. Better aesthetics of product with dry methods.
62	Takes twice the time and increases cost.
110	Not company policy to use wet methods.
122	Doesn’t do a good job, takes longer.
86	Prefers use of vacuum sanders.
257	Too slow, the finish is not as good.
63	Not necessary.
94	Aesthetics. Wet methods don't give as good-looking a result.
121	Too slow.
108	We don't do any taping.
254	No need; time.
260	We do dry vacuum sanding.
91	We use dustless sanders.
123	Dot not need.
88	Use shopvac/vacuum sanders instead.
46	We use vacuum.
124	See note.

267	The worker just cannot get a good finish with this method.

Q4. Continued

149	We don't finish the drywall we just hang it.
168	Usually only with remodels, not new construction.
127	No idea.
170	Don't like the quality of the finish.
3	Slower.
213	The finished thing is not as smooth using the wet method.
196	Prefer dry methods to maintain integrity of drywall.
186	Does not work well.
228	Quality control-not as nice as finish.
242	Time-consuming and ineffective.
195	We don't do that scope of work.
132	Slower and does a bad job.
17	We do new construction.
61	We don't do sanding.
193	Use portable sanding vacuuming very little dust.
60	Easier to sand drywall while dry. Avoids wet methods.
192	Too slow.
134	Not used in this firm.
198	Not our style of finishing.
171	Not productive in commercial work.
24	It puts moisture back into the board.
169	It does not do a good job.
51	Just use around places where there are computers, etc.
190	See F4 note.
26	The only trouble could be when sanding near computers, etc
31	No reason.
165	Time.
138	We do new construction.
27	Do not really understand the question, we used to sponge.
58	We use hand vacuum sanders.
246	Just use regular sandpaper.
262	Hard to apply.
215	Don't need to do new construction.
57	Does not produce good product or finish.
239	We use vacuum sanders.
224	Tapers do that.
146	Doesn't finish off as well.
163	F4 note.
55	With commercial jobs not a factor except where there are computers.
54	Use vacuums instead.
147	We use dustless sanding.
199	We don't sand, don't do the finishing.
41	Cost prohibitive.

28 Use vacuum system instead.

Q4. Continued

223	Mainly works with new buildings, not necessary.
207	It is not as easy.
38	Just don't.
40	It’s not necessary or cost effective
16	Can't sand wet dentist office.
161	Not common practice.
45	We use vacuum sanders.
53	Wet methods are costly and ineffective. Prefer to avoid them.
10	Inexperienced in them. No need.
151	Not industry standard procedure.
29	Not used.
178	Never needed it. We don't sand between coats.
174	We are normally in an environment that this is not needed.
164	Just don't need to.
200	Time.
216	Not necessary in new construction.
235	Too slow.
201	Don't know anything about wet methods.
241	Productivity problems.
234	We use vacuum sanders.
48	Use other methods, avoid wet methods as messy.
172	Productivity and the amount of mess, it’s easier to clean up.
154	Not part of our routine.
202	We don't do the finishing. Taping sanding, etc.
181	His crew does not do the sanding; paint crew does sanding.
37	We use vacuum sanders.
15	You can't sand wet mud.
175	We use vacuum sanders when control of dust is needed.
19	We don't sand.
270	Use other methods.
156	Not the practice with our firm.
205	Not company practice.
174	We work mostly in new construction and therefore the customer is not worried about the dust.
157	Sometimes water not available. Not our standard method.
180	Production would be lower. Wet methods make walls too soft.
47	Industry standard.
219	Mostly new construction.
158	Open air construction, not used.

Q5. Does your firm use respiratory protection such as respirators or masks when workers are sanding drywall compound always, often, sometimes, rarely, or never? Responses to "rarely" and "never" provided.

Respondent #	***Response***
246	Just preference.
195	We don't do the finishing work.
61	We don't do sanding.
199	Don't do the finishing.
149	We don't do the finishing.
93	Don't see, not our portion of the work.
19	We don't sand.
257	Perceived risks.
66	Company does not sand only install.
215	Only when in an occupied space.
108	No dust at our jobsites. Subcontractor cleans it up.

Q6. Does your firm use pole sanders as a means of keeping workers removed from dust always, often, sometimes, rarely, or never? Responses to "rarely" and "never" provided.

Respondent #	***Response***
231	We use dustless sanders, Porter cable.
224	Not our job.
149	We don't sand because we don't do the finishing.
48	Already work on scaffolding.
222	Pole sanders don't keep dust from workers.
132	Uses them but not to keep workers from dust.
66	Company does not sand only install.
61	We don't do sanding.
225	Does not protect from dust; it still comes down from ceiling.
91	Use dustless sanders only have one pole sander in our place.
118	Not our routine.
215	We do new construction.
40	We use them but not for means of keeping workers removed.
74	The dust factor we use vacuum sanders.
181	His crew does not sand; paint crew does sanding.
108	No sanding at our jobsites.
34	We use dustless vacuum sanders.
199	Don't do the finishing.
19	We don't sand.
85	Ineffective. See F4 note.
195	Don't do the finishing work.
202	Don't do the finishing.
234	We use vacuum sanders to capture the dust.

Q7. Does your firm use ventilated or vacuum sanders as a means of controlling dust during sanding always, often, sometimes, rarely, or never? Responses to "rarely" and "never" provided.

Respondent #	***Response***
210	Convenience-requires setting up more equipment.
39	Not feasible we do condos not much dust with new construction.
106	Just don't do it.
41	Don't own any.
215	No need when not occupied.
164	Only if the area is occupied.
178	No electricity on our jobsites. New construction.
165	Time.
38	Don't have that much dust.
16	New construction.
95	Only use in dust controlled areas, finished areas.
85	Ineffective. See F4 note.
204	We do new construction.
43	We often work in open buildings, no need for these.
216	Cumbersome. Time-consuming.
96	Disappear from the worksite. Hard with to work.
158	Open air construction, not needed.
61	We don't do sanding.
219	Never had need for one.
47	Not an issue.
156	They leave ruts in the finish.
36	We don't have them.
75	Works didn't like them; the name of the game is production.
66	Company does not sand only install.
102	Never seen one in use except in trade ads.
264	See F4 footnote.
40	We only work in new construction not worried about.
181	His crew does not sand; paint crew does sanding.
17	We don't need to.
108	No sanding at our jobsites.
206	Practicality.
183	Open air/new construction.
202	Don't sand don't do the finishing.
154	Not our standard operation. Open-air construction.
79	New construction no concern.
48	Industry standard in this area.
31	No reason.
153	See F4 note.
185	Not familiar with them. Mainly do new construction.
199	Don't do the finishing.

Q7. Continued

222	Don't work at controlling dust; ineffective.
93	Not our portion of the work.
186	Not necessary unless you are doing houses.
5	Does not do as good of a job and they take longer.
149	We don't do the finishing.
267	You just can't get the workers to do a good job with these.
188	We just don't.
223	No reason to use them, does not find them helpful.
119	We have just not invested the money yet, it's pricey.
97	Work in areas too big to use these.
143	Prefer tape.
138	Don't even own one.
224	Don't do that.
62	Business too competitive, too costly and time-consuming.
59	Cost.
60	Has no reason.
136	Don't have any.
127	Only use in open remodeling.
194	Not available.
121	Like to feel the work and feel the finish produced.
63	Not necessary.
249	Best used in public areas use otherwise not happy with them.
19	We don't sand.
195	Don't do the finishing work.
254	Clog up too much.

Q8. Does your firm use a low-dust drywall compound or setting compound to reduce dust levels always, often, sometimes, rarely, or never? Responses to "rarely" and "never" provided.

Respondent #	***Response***
195	Don't do the finishing work.
196	Not familiar with product.
19	We don't sand.
22	This is a fairly new product, we have never tried it.
96	Cost.
193	Not heard of this.
84	Haven't tried it yet, new to market.
190	Not yet in use with this firm.
189	Product not used in this firm; unknown.
27	Not familiar.
188	Just use regular compound.

Q8. Continued

83	Just usual compounds.
186	Doesn't know about product.
185	Not familiar with this type of product.
199	We hand the drywall, tape, then float them out. Don't finish.
99	Did not know it existed.
184	Not available in the company's area.
32	Just don't know about it.
183	New construction.
181	Paint crew would use this; his crew does not sand.
202	We don't do the finishing work.
102	Not familiar with them.
203	Used it a few times not sure how we like it.
34	It is something new.
180	Not available.
178	Try not to sand at all. We actively avoid sanding.
103	New to market.
204	Not yet.
177	Hasn't been around long enough.
176	It's something new.
207	Never heard of it.
175	The price.
18	Not aware of product.
173	20% cost over regular compound. Use in delicate situations.
106	Just don't do it
210	Not our worker's preference.
39	Not much dust in new construction.
95	Not familiar with these materials.
211	Use multipurpose mud instead.
17	We don't need to.
212	Never have no reason to use it. Do you eat the same thing for breakfast? You probably eat the same few things. Construction is the same way until we have the new product we just keep using the same thing over and over. I have had no reason to use a low dust drywall compound.
170	Don't like the quality of the product.
169	Not familiar with this product.
108	Don't do sanding; don't need to use compound.
213	Just started using it was given to me free.
40	Not cost effective.
21	I have never heard of this.
71	More expensive.
165	New product tried it maybe once.
164	New product, have not tried.
42	Too new.

Q8. Continued

215	We are about to try that.
163	New to market. Not familiar with it.
88	New product, trying it. Works well in some cases.
160	Tapers don't like it.
44	Too new to market to be using.
158	Not in our specs.
217	Don't know of such.
111	New to me (unfamiliar with product).
157	We have good tapers, don't need to use drywall compound.
219	New to us.
13	Not used it, not really familiar with it.
156	Not used yet; new to market.
66	Haven't heard of it.
47	Industry practice.
154	Not something we use in open-air construction.
9	It has not been before us very long.
153	Happy with current product. "We stick with what works for us."
51	It is not available here yet.
151	Not industry standard to use this.
116	New product, hasn't been proven yet.
149	We don't do the finish work.
117	New product just out, have not tried it yet.
53	New product on market; very limited experience with it.
8	Cost.
118	More expensive.
62	Too costly. Taping is just as effective and cheaper.
119	We are leaning that way.
137	Just became available.
224	Don't use it.
87	Not familiar.
63	We were just introduced to this about a month ago.
132	New; sees it infiltrating market as up and coming product.
166	Unaware of it.
121	Prefer to use USG Blue Spackle.
226	Whatever is on market.
4	Not much on the market that has low dust.
3	Not used in relation to dust.
61	We do tape and bed.
228	Not as nice a finish.
229	Not yet.
127	New product not familiar.
123	Not using yet.
120	See F4 note.

Q8. Continued

230	Uses whatever is on the market at the time.
138	New product, have not tried it.
250	Don't believe it works - not as good a finish.
267	New products not tested.
254	See F4 note.
232	Don't sand as easily.
263	Rarely, because of its newness.
260	It is a new product.
234	I have not heard of it.
258	Just the regular Durabond and other products.
257	Not aware of any.
256	Not familiar.
241	Does not see much of a difference with other products.
235	Experimenting with them now.
253	Not familiar with it.
266	It's new technology.
248	Quality and cost of product.
245	Not familiar.
243	Never heard of it.
238	Tried it didn't like it. See F4 footnote.
242	See F4 note.

Q9. Does your firm use any other methods of controlling dust generation other than those I've mentioned? Responses to "yes" provided.

Respondent #	***Response***
239	We use tarps, etc to close off areas.
153	See F4 note
155	See F4 note.
152	Visqueen.
150	Ventilation.
159	Sometimes we encapsulate a room with poly (plastic).
163	"Poly off the area" (polyvinyl sheets) and contain dust.
146	Straightfall sanding compound useful.
94	Negative air rooms.
166	Dust barriers like Visqueen.
144	Ventilation.
170	Use Dustdown compound when sweeping work area.
245	We use room dividers.
139	Install temporary barricades. Use Zipwall pole system.
137	mask off door ways to contain dust.
246	We use fans.

Q9. Continued

134	Tarps and barriers installed by tapers.
247	Fans, dust barricades.
175	Barricades.
129	Containment with barriers (dustwall or visqueen).
128	Barriers.
119	Put up perimeter stuff, barriers.
177	Plastic to separate rooms during remodels to protect clients.
221	Firm uses a unique no-sanding system ("dry trowels").
220	Negative air machines.
107	Ventilation at work sites.
105	Wet sanding.
222	Opening windows at worksite.
101	HEPA filters installed in doorways.
99	Hang visqueen to keep dust levels controlled.
180	Ventilation.
253	Barriers.
92	With remodels, install barriers and do draping.
87	We tarp the area, close it off.
182	Dust barriers.
187	We use air circulation fans that draw the dust out.
190	Barricades, high-grade air filters in sensitive areas.
86	Ventilation systems.
85	See F4 note.
195	We vacuum the dust.
81	Ventilation.
234	We use zipper plastic to close off the areas.
258	Clean up daily and ensure use of proper procedures.
78	Zipwall and company device. See f4 note.
76	Clean sweep.
74	Sometimes we put dust barriers.
261	Negative air systems.
71	Hepa filters.
208	Visqueen and section off areas.
66	A Hepa filter system will be used if work is done in hospital.
65	Uses dust partitions like zipwalls.
62	Enclose work areas with polyvinyl (zipwalls).
57	Uses fans for cross-ventilation.
262	Sponging around computer areas.
56	Uses barricades-specifically zipwalls.
210	Tarping off areas (no specific product).
54	Fans to blow it outside.
49	Dust barriers, it all depends on the setting.
47	Build temporary partitions.
265	Skill and experience.

Q9. Continued

44	Negative air machines.
42	Barricades or quipwalls.
250	Masking off areas with barriers.
39	We use fans.
36	We apply drywall so you don't have to sand.
24	Use Visqueen and zipwalls to keep dust controlled.
103	More coats.
269	See F4 footnote.
12	Low dust material new to market.
11	Big fans to ventilate better.
4	Poly barricade.
270	Air exchanger for hospital use.
3	Negative air. Vacuum or sweep afterwards.

Q13. Is there anything else you can tell us about your experience with drywall dust or drywall dust control technologies?

Respondent #	***Response***
220	I think you got it covered.
11	Electric sanders with vacuums have been our best customer satisfier and we feel it is the safest for our workers. It sucks the dust.
269	He is happy to see the new heavy mud to control dust.
9	We are using vacuum sanders more and more and finding that it makes a difference, also what kind of sanding machine you use, and the type of screen makes a difference.
225	Dust goes EVERYWHERE and is hard to control, even with visqueen barriers. It's like talcum powder. Sanders get torn up, vacuum sanders get ruined. Dust ruins productivity. Filters get clogged and we have to slow down to replace them.
219	Makes you turn white. Necessary evil of the job.
10	No.
5	The more skilled the worker is with installing drywall the less sanding needs to be done which reduces dust.
224	Not a concern.
221	Has been in business doing drywall for 30 years. Does not see drywall dust as a particular problem, just part of the job.
223	It's part of the job. Messy, dirty.
3	Took asbestos out of drywall-good.
270	Becoming more of an issue with OSHA.
213	The vacuum really cuts down on dust and for finished product hands with sponges work the best.

Q13. Continued

211	Follow job specs as required for dust-free environment. Follow OSHA specs and control for exposure of others in the work environment. With remodels, barricade off areas using Visqueen or other polyvinyl products.
208	Dust control getting better. More methods available.
227	Does most of their work in hospitals. Extremely important that we institute dust control methods. Setup and cleanup is a major part of what we do.
203	Just interested in seeing how that low dust drywall compound is going to do.
216	No.
197	Some guys take precautions, some don't. Some guys poke holes in their equipment and don't take care of it.
196	Firm is located in Vegas area so has to deal with extreme conditions. Climate extremely dry so dealing with particulate matter is a concern.
15	We're using taping tools not hand trowels but boxes, cut down on amount of mud we use. More control.
12	Ongoing process - always new products and new methods to try.
151	No.
57	No.
1	No
234	We have come a long way from the old days. Much improvement.
23	No.
191	Drywall dust is a pain; wife doesn't like it coming into the house (always on his shoes). Recommend using common sense in dealing with it. Expressed great concern about his workers and making sure they are safe in workspaces generating a lot of dust in the air.
136	Part of the job.
47	None.
24	Try to keep it to a minimum with respirators and zipwalls.
90	No.
154	Not a big problem with our workers. Our guys work out in the open and don't have problems with dust.
87	New vacuum systems called Bazookas they suck the dust right up.
86	No.
92	Safety programs and training help limit dust exposure. This is mainly a commercial construction company, so there is better ventilation with open-air projects. Dust is more of a problem in remodels. Have to schedule worker clean-up time at end of each day. Installs washing facilities at worksites. Too much dust=too much use of joint compound (worker method problem). Quality of joint compound is also an issue. Some compounds are too flaky and should not be used. Can judge the quality of worker productivity by the amount of dust they generate.

Q13. Continued

85	He has years of experience in working with drywall. There are ways to do the work to minimize the dust problems. His workers see dealing with dust as part of the job. Puts up the Visqueen to block the dust and throws it away at the end of the job.
187	For schools or hospitals we recommend Imperial Board it is a thin five eighths inch coated plastic board, there is very little dust involved with installation, looks like plaster.
28	None.
253	Part of the job.
185	No.
29	None.
94	Starting using new joint compound this week. Don't know how effective it is yet.
241	(Safety manager) Workers have problems with goggles-dust sticks to the lenses, blocks their vision and blinds the workers so they can't see what they are doing. I sample the air regularly when workers are sanding overhead and they have a 4 hour window to do their job to keep it out of their respiratory systems. Regularly measures the PEL levels.
31	None.
183	Firm does new construction. Drywall dust not a problem.
181	His crew generates drywall dust by cutting, screwing and handing drywall. No sanding is done by him. All sanding is done by the paint crew.
180	They need to wear their respirators.
84	No.
35	I handle all our workman's comp and in all our years in the business we have never had any health problems from dry wall dust.
235	No.
96	Old school company (60 years in business). Workers deal with the dust – it's part of the job. Spackle creates the dust - we avoid using it. Homeowners layer it on and create dust problems.
36	The main thing is to put the mud on so you don't have to sand. We use sponges with rough sides to get edges so not to have to sand. We put a fan in the window to blow dust out so it doesn't go in the rest of the house. The fan has to fit tight in the window so air has to flow out (negative air system). We use plastic door openers with zippers.
83	Control of drywall dust leaves a lot to be desired. Need to develop better products to keep dust levels down.
178	We strongly discourage sanding. We tell out people to do it right the First time and if they can't, they don't do further work for us. Sanding creates dust and we keep our jobsites as dust-free as possible.
97	Company does mainly open-air construction. Maybe 1% of work done with hospitals and dealing with drywall dust.
52	No.

Q13. Continued

237 Keep project areas clean daily. Have work crews specific to doing cleanup and keeping job site clear of dust as much as possible. Try to stop it before it becomes a problem.

172 Its a battle on every job. Trying to keep it clean takes 1 or 2 laborers to go in every day and sweep up the place.

150 More problems with remodels and customer complaints. [This firm handles mainly open-air construction with minimal customer complaints. Heaters circulate the dust in residential homes. In construction uses lots of visqueen and zip poles on barricades. Uses white zisqueen to block the view on construction sites (stop the onlookers and gawkers at construction sites).

81 Does 90% of work in veneer plaster which has no dust. In mid-80s drywall dust was more of a problem. Recommends use of pole sander with a vacuum attachment to get rid of most dust. Trains their workers to minimize dust in the work environment.

39 Where dust is a no-no we vacuum as we go.

99 Drywall dust ruins the tools. It's so powdery it gets into EVERYTHING. We try to limit the number of cuts we make in the drywall to limit the dust production. Drywall dust is part of the job and cleanup is also part of the job.

171 Asbestos was the big problem. Now that it is out of the drywall, it's no longer a problem.

170 No.

168 Specs determine which work methods are used. We do what the job requires.

167 We just ask them to always wear masks.

166 No.

236 Unscrupulous contractors make it difficult for legitimate businesses. Met with the Governor yesterday and witnessed the signing of a bill making it illegal to transfer risk to someone else. Some firms do not pay their payroll taxes or insurance making it harder for legitimate firms to compete. The less reputable firms do not follow proper safety precautions.
or maintain good working practices. Respondent would be willing to offer assistance in any way he can; he expressed his gratitude that this study was being conducted.

263 Dry wall dust is only in the hands of those that control it and we try to control it because we want our customers back.

163 Worst part of the job. Clean-up time needed to keep the customers happy - "dust is a real pain in the butt."

80 In last 5 years, industry has become more aware of silica products and more work has been generated in removing it. Sensors are placed on employees to keep management aware of silica dust levels on workers. OSHA wants management to keep tabs on it.

Q13. Continued

100	All tapers are union regulated and very stringent in their methods. Dealing with drywall dust is more of a problem for anyone not wearing a mask (other contractors or people walking around worksite).
42	Rely on vacuums for dust removal. [Interviewer asked for specific company and he recommended Porter-Cables.]
162	It'll always be there (dust).
161	Just part of the job.
160	No.
45	It has always been there and will always be there.
78	Recommended a good contact for information: AWCI at 703-538-1600 (national organization of wall and ceiling installers that publishes for the industry).
158	No.
265	It gets on the carpet.
44	Build temporary partitions in rooms; build anti-rooms and use negative air machines.
157	Safety glasses help.
156	Workers rely on taking precautions to control for dust. Put up barriers to stop it before it becomes a problem.
155	Inexperienced workers have dust problems. Just started 6 months ago Using Quickset joint compound; recommended by our equipment supplier. It's been good with dust protection. Vacuum sand poles are good in occupied areas; keeps dust out of air units.
101	"No. You covered it all."
62	Drywall dust filters thru EVERYTHING. Has more problems doing work in offices. Offices want us to do drywall work after-hours when the workers are gone. Because the drywall business is so competitive, he relies on tapes, masks, and hats.
142	No.
258	It's there, part of the job. We use special clean-up procedures and specific procedures on the job to deal with the dust.
49	Drywall dust sucks!
259	Vacuum sanders helpful in occupied areas.
107	Dust is part of the job. Wear dust protection and you are OK. Used to have a problem with asbestos dust, so drywall dust seems better by comparison. There are all kinds of dust at job sites, not just drywall dust. Protection is required on job sites.
153	Dust is part of the job; I've done it for 33 years. The trick is to put sanding compound on smooth and then you don't need to sand it. The more dust, the more inexperienced the worker.
108	No drywall dust problem in this firm's work.
48	No.
50	It is a pain in the rear but you all have it covered.

Q13. Continued

102	Never had problems with drywall dust. Worked with drywall since 1958. Dust is part of the job.
89	Air quality is carefully monitored because of union standards. Union ensures proper protection is used in workplace to lessen health impact of drywall dust. Workers who know what they are doing don't have health problems with drywall dust. "If you know what you are doing you don't have a problem."
88	"Not really. You covered all the major methods."
134	No.
68	The cords on the vacuum sanders are not long enough but they are a cool idea.
116	Eliminate as much sanding as possible touch up more.
148	No.
147	You HAVE To use some kind of respirator, which is imperative.
53	Has long experience working with drywall; sees little change in market or methods. Would like to see improvement in dust control.
146	Masks important in hanging drywall.
59	No.
54	Visqueen dust off to make a bubble with it. Also try to sand it off with a vacuum. Hard to deal with dust. Use of water causes a problem; it's ineffective in removing dust. Use of sponges is not cost-effective or productive in removing dust.
74	The products have gotten better and we have learned how to control it better over the last two years.
242	Firm specializes in Vegas casinos. Does multi-million dollar projects with a high expectation of excellence. Have witnessed people with serious health issues due to gypsum exposure (long-timers). Even a dust mask is not sufficient with fine particles.
252	I put floor sweep on the base boards and floor to keep dust down. I put water on the base of the walls and on carpet to keep dust down.
103	Dust goes everywhere at worksites. Vacuum sanders don't work with medium-grade dust products (drywall spackle comes in light, medium, and heavy grades.) Sanders only work with heavy-grade product and manufacturers neglect to tell companies this. We isolate work areas with negative air return systems and temporarily tie off areas. Subcontractors are supposed to isolate work areas before we arrive by setting up negative air systems. We especially need to control for dust in hospital worksites.
56	Drywall dust causes more problems with workers' hearing than with their respiration. Workers need to wear earplugs.
72	No.
143	No.
111	Once asbestos was out of the dust, dust not a problem anymore. It's just part of the job.

Q13. Continued

139	Drywall dust is a problem - once you get it, you can't get rid of it.
132	No.
120	Dust more of an issue in remodels. This firm is 90% open-air construction. Patch & repair generates the dust problem.
110	No.
118	No.
230	Proper protection is key. Lead guy is key to keeping the workers protected and using proper techniques. Work is better without the asbestos (had been used as a firming agent).
260	I wish they would come up with better methods.
129	Drywall dust is a nasty animal - gets everywhere.
249	The methodology has not changed in many years. Hoping for new equipment that is not so bulky and sanders that will perform better.
124	No.
60	No.
65	Tries to keep up with new methods.
112	Have to live with the dust, it's part of the job.
114	No.
115	Dust amount specific to type of drywall being installed - high impact drywall the worst for dust. Cutting methods also determine amount of dust generated. Cutting knives are clean; sanders generate dust.
121	Wife does not like it when he does work around the house. She gets a real "taste" for what he does and the dust it creates.

Supplemental Comments Provided by Respondents for Each Survey Item

Q1. First, how would you rate the negative impact of drywall dust on your firm's productivity? Would you say that it has had a great impact, some impact, not much of an impact, or no impact?

Respondent #	***Response***
179	Firm does new construction. Drywall dust not a problem.
92	Commercial contractor; very few remodels done. Mainly do open-air projects.
94	More of an impact in remodels and hospital work (requires better dust control). Easier to deal with in new construction.
189	Specializes in new construction. General contractor prepares workplace to minimize dust for his crew.
121	It's part of the job.

Q1. Continued

216	Mainly new construction.
96	Part of the job.
190	Mainly does new construction.
134	Only an impact in remodels.

Q2. How would you rate the <u>negative</u> impact of drywall dust on customer satisfaction with your firm's work? Would you say that it has had a great impact, some impact, not much of an impact, or no impact?

Respondent #	***Response***
231	We do commercial.
172	97% of our work is done prior to owner occupancy.
166	Keep a very clean work environment.
134	Only an impact in remodels.
121	They realize it's part of the job.
60	Depends on type of customer - no impact with new construction. But with remodels, great impact because customer has to live with the dust.
190	Mainly new construction. Does have some impact in remodels.
185	Depends on whether it's new construction or remodels. Remodels involve customers who may need cleanup. New construction does not generate problems.
154	Firm mainly works in new construction and rarely hears from customers about dust.
53	Customers rarely see work in progress. Only occasionally see spot touchups which generate little to no dust.
178	New construction only.
235	Mainly does hospital renovations.
85	Big problem with remodels.
92	Commercial contractor.
262	95% new construction.
230	computers, residential.
227	Hospitals.
99	Mainly commercial work. For customers, more of a nuisance.
96	Customer never sees the dust; we clean it up and it's gone by the time they are around.
112	No customer likes it.
72	Mainly works new construction, doesn't do remodels. Customers aren't exposed to drywall dust.
84	Most impact with remodels. Little impact with new construction.
71	Commercial not much of an impact...remodeling and new residential construction great impact.

Q2. Continued

253	New construction; not a concern.
78	More of a problem in remodels; not a problem in new construction.
107	Mainly new construction.

Q3. Would you say that drywall dust poses a great threat, somewhat of a threat, not much of a threat, or no threat to the health of the workers in your firm?

Respondent #	***Response***
196	[respondent is safety coordinator at firm.] Has concerns about long-term effects of airborne dust; scientific data is currently inconclusive. Has specific concerns about silica in drywall dust.
190	More of a threat when workers do not wear their protective gear.
242	Personally knows several workers with health problems due to drywall dust. Has experienced his own respiratory problems from his own days out in the field.
216	Mainly new construction. More of a problem with remodels.
185	Depends on worker's involvement with dust. Some workers are never around the dust; other types of workers do the sanding and cleanup and need protection. We provide protection, but it's up to the worker to use it.
85	Company workers are acclimated to the dust. It grows on them and has to be removed. It's part of their bodies and workers are experienced in dealing with it. It's part of the job.
88	Use protective methods to lessen impact.
121	Used to be more of a threat when asbestos was part of the dust. Better dust control technologies now.
107	Requires protection.
96	Follow union regulations to minimize threat. It's up to the workers to use the proper methods and protection.
94	Use methods to minimize threat.
78	Varies based on the specific project. Varies on compliance of worker in wearing protection measures.
102	Wear protective gear.

Q4. Does your firm use wet methods when sanding drywall compound always, often, sometimes, rarely, or never?

Respondent #	***Response***
181	Firm strictly Cuts, hangs and screws in drywall. Sanding done by painters. No sanding done by his crew.

Q4. Continued.

Respondent #	***Response***
57	Anyone who tells you wet methods work is lying to you.
190	Does not give a good result. Time-consuming, costly, difficult, not the preferred method.
163	Only use wet methods in computer or sensitive areas. There are cost and quality problems with wet methods. We don't recommend this method.
40	Don't want water near an unfinished unpainted surface.
124	Not familiar with wet methods. Aware there is a new USG compound on the market but has not tried it.
172	Easier to dust than it is to clean up a wet mess.
174	Work mostly in new construction and therefore the customer is not worried about the dust.

Q5. Does your firm use respiratory protection such as respirators or masks when workers are sanding drywall compound always, often, sometimes, rarely, or never?

Respondent #	***Response***
26	Use wire masks by 3-M, Niash approved.
96	At worker's discretion. People who have been in the industry long don't see the need.
190	Protection provided; up to workers to use it. Workers dislike wearing goggles because they fog up and get dirty, impairing vision. Don't like lugging around the respirators.
198	Equipment always available, but use not mandated. Up to the individual to use the equipment.

Q6. Does your firm use pole sanders as a means of keeping workers removed from dust always, often, sometimes, rarely, or never?

Respondent #	***Response***
96	Depends on the job.
85	Just to reach work area, not to control dust. Workers come out covered in dust even when working with pole sanders. (Workers appear white.)
180	Pole sanders cause dust.
112	Depends on specific job and the need to reach high spots.
78	Varies based on project.
168	Pole sanders are not used to keep workers removed from dust, but to reach inaccessible areas.
210	Depends on the job and the room we have.

Q6. Continued

225	Does not protect workers from dust. It still comes down from the ceilings.

Q7. Does your firm use ventilated or vacuum sanders as a means of controlling dust during sanding always, often, sometimes, rarely, or never?

Respondent #	***Response***
111	Depends on the job. If the site needs to be kept clean, use vacuum sanders.
53	Only used for small area touchups.
94	Depends on particular project and accessibility.

Q7. Does your firm use ventilated or vacuum sanders as a means of controlling dust during sanding always, often, sometimes, rarely, or never? Responses to "rarely" and "never" provided.

Respondent #	***Response***
85	Requires use of electricity which is not always available. Requires certain level of skill and worker may not be able to control vacuum sander (possibly too dangerous for most workers). Equipment sometimes too difficult to handle in small work spaces.
264	Use only in occupied areas. They are very cumbersome. We try to stay away from using them and do mostly new construction.
153	They don't work at all. It's an expensive piece of equipment that we have sitting in the office that never gets used.
40	Control of where the dust goes.

Q8. Does your firm use a low-dust drywall compound or setting compound to reduce dust levels always, often, sometimes, rarely, or never?

Respondent #	***Response***
134	New USG product being used.
124	USG is promoting the use of a new product that promises to create heavier clumping particles that fall to the floor instead of creating fine airborne dust. Treated firm members to lunch to tell them about it.
136	Not familiar with them.
168	Not for dust control, but time constraints.
110	Not familiar with the product.
59	New product. Seems to be helping.
72	New to market. Limited experience.
238	He said they did not like the new drywall compound, it is too hard, can't get it to feather just right. "We do slick work. With textured work it would probably be alright."

Q8. Continued.

Respondent #	***Response***
120	Not currently available in respondent's market (Colorado). Respondent has only seen it advertised in the trade magazines.
254	More time consuming. Dries too hard and requires more work. This sometimes damages existing work. Glazes over during drying process.
242	Workers don't like it - produces excessive air bubbles and a poor finish. Workers think the company still needs to work the kinks out of the product. He has used it himself at home and does not like it.

Q9. Does your firm use any other methods of controlling dust generation other than those I've mentioned?

Respondent #	***Response***
108	All the dust is gone by the time respondent's firm does their work.
146	Straightfall.
85	Prepcoat (commercial product) applied in 98% of cases. Leaves a glasslike finish. USG product.
49	If you're working in a hospital you need more control over the dust verses working in a new mall.
155	Visqueen to block off areas. HEPA filters used in hospitals and areas with computers. Negative air ventilation to block dust flow.
78	Company has made their own device of zipwalls attached to a pole using visqueen to control dust.
153	Tape off rooms and protect the heat register. Dust in the heater voids the warranty. Control for ventilation.
269	He said three things were important. The additive in the dry wall compound, the negative air pressure (using fans) and control and containment (dust).He mentioned dust walls and electromagnets it sticks to vinyl. Also they create double dust walls (VisQueen) to protect the work area.

Q10. How many employees does your firm have?

Respondent #	***Response***
24	Overall total.

Q11. Are your employees affiliated with a union?

Respondent #	***Response***
59	Would not have any workers if he hired union labor.
155	Used to be affiliated with union years ago.
198	Not drywall tapers. Everyone else is.

Q12. Does your firm hire subcontractors to perform drywall finishing always, often, sometimes, rarely, or never?

Respondent #	***Response***
163	Illegal.
196	Respondent's company is the sub.

Appendix G: Study 3 Content Analysis Code Definitions

Code	Code Definition
Ease of Learning (EL)	Comments that pertain to the user's ability to begin using the technology. Comments that pertain to the user's ability to arrive at a feeling of proficiency while using the technology.
Ease of Use (EU)	Comments that pertain to the user's ability to accomplish the task as instructed, once familiar with the technology.
Perceived Productivity (PP)	Comments that pertain to the user's perceived ability to employ the technology to accomplish a set amount of work in a given unit of time. Comments that pertain to the user's perceived ability to employ the technology to accomplish a desired quality level of work in a given unit of time.
Perceived Comfort (PC)	Comments that pertain to the user's observations of physical sensation: pain, fatigue, muscle stress or strain, or lack thereof.
+/-	Denotes whether the comment was a positive or negative one pertaining to that code

Appendix H: Study 3 Coded User Responses

Tool	Coding Unit	Code	+/-	Gender
Pole	Awkward to hold the pole, one arm became more fatigued	PC	-	M
Pole	Easier to reach higher places	EU	+	M
Pole	Less control of the sanding in general	EU	-	M
PC	It was heavy and awkward because of the vacuum head.	PC	-	M
PC	It missed one spot because of the rotation	EU	-	M
PC	It was easy to move down or to the left but hard to move up or right because of rotation.	EU	-	M
Wet	Comfort level was identical to the (block) method	PC	+	M
Wet	I don't think I used the block correctly	EL	-	M
Wet	once it picked up enough sanding dust, it became ineffective in sanding	EU	-	M
Wet	It also got the dry wall very wet	EU	-	M
Wet	I think this would reduce the quality of the sanding	PP	-	M
Block	Sanding higher places in general fatigues my arm, I don't think it had to do with the technology	No code		M
Pole	The sander flipped on me a few times, denting the wall	EU	-	M
PC	Fairly easy to use up higher	EU	+	M

PC	Very difficult to use shoulder level and below	EU	-	M
Wet	When I initially applied the wet block it soaked the mud, and the mud clumped n that spot and stayed there	EU	-	M
Wet	The mud also clumped up in the sanding block which seemed to reduce its effectiveness	EU	-	M
Block	Took more force than the previous sander	PC	-	M
Block	More tiring	PC	-	M
Block	Also harder to use at the bottom end of the board	EU	-	M
Pole	It was easy to use on the hight part but more difficult on the lower part	EU	+/-	M
Pole	I would not like to use this for a large sanding job	PP	-	M
PC	The only problem is that you cannot see the results right away b/c of the larger sanding head and it could lead to mistakes	EU	-	M
Wet	I did not like the sponge: the water is likely to spill and make a mess.	EU	-	M
Wet	Plus, I felt that it would take longer to complete something with this	PP	-	M
Block	This would be good for patyching walls but not for large areas	PP	-	M
Pole	Definitely required a lot of effort, especially in the shoulders	PC	-	M

Pole	I had to switch hands on the pole to keep from fatiquign one arm more than the other	PC	-	M
Pole	The flex-joint at the pole/sander connection is strange and flimsy, making the task harder	EU	-	M
Pole	This technology would be a plus for high overhead sanding though			M
PC	A lot of effort, especially in my chest (pectorals)			M
PC	Seemed a lot less messy than the wet or block sanders	EU	+	M
Wet	Requred a lot of effort, especially in the shoulder and tricep areas. Switched arms to reduce fatigue	PC	-	M
Wet	Water was confusing, didn't seem to make any difference. There was still a ton of dust	EL	-	M
Block	Lot of shoulder effort, very tiring	PC	-	M
Pole	I felt like I was further from the falling dust than the other two tools.	Not coded	+	M
Pole	If used improperly, it would tend to smack the wall causing a large "poof" of dust	EU	-	M
Pole	Hard to sand directly in front of yourself	EU	-	M
Pole	Had to stand at angle to get entire area sanded	EU	-	M
PC	It was big and clumsy—harder to control	EU	-	M
PC	I wouldn't use it because I don't think I would have a job big enough to require so much equipment, but I	PP	-	M

	would consider in an industrial setting			
Wet	clumpy and sticky	EU	-	M
Wet	Seemed like it got worse in terms of dustiness the longer you sanded without dipping it in water	EU	-	M
Block	This seemed to be the most manual style of sanding. I switched arms once too, as my arm felt a bit fatigued.	PC	-	M
Block	Dusty	NOT CODED		M
PC	A larger area to sand would have been better. I finished the task in about 2-3 mins	PP	+	M
Wet	More mess on the hands with this method	EU	-	M
PC	Good workout!	NOT CODED		M
Wet	Much more fun that I thought	NOT CODED		M
Block	Lots of dust I can see	NOT CODED		M
Pole	This ws the most frustrating of the technologies. It was very hard to keep the sander flate on the wall	EU	-	F
Pole	Also, it would not glide up and down the wall very well	EU	-	F
Pole	I felt like I was fighting with it the entire time I was	EU	-	F

	using it			
PC	This particular technology was clearly more effective/efficient in terms of the sanding task	PP	+	F
PC	however, it was very heavy and bulky	PC	-	F
PC	It didn’t feel like I could switch my hand/arms to get more comfortable once I got tired	PC	-	F
PC	I don’t think that I would have been able to sand a whole wall with this technology --- I would have been too tired	PP	-	F
Wet	This technology was small enough so that I could change positions or swithch hand quite easily.	PC	+	F
Wet	I felt like this technology was making the wall survace smother faster than the first technology.	EU	+	F
Block	This technology allowed me to easily change the position of my arm/hand or switch hands once I got tired or uncomfortable	PC	+	F
Wet	This was the best method. I felt like I have the most control of hand/arm position while doing the sanding task	EU	+	F
Pole	This was the worst because it was hard to keep smooth movement up and down the wall	EU	-	F
Pole	This tool seems very old fashioned. You couldn’t do this task for too long without getting tired	PC	-	F

PC	It was easier to get the job done with this tool	PP	+	F
PC	I didn't feel that I was doing it correctly	EL	-	F
Wet	I like that there's less dust but it's too wet and it caused a lot of building up on the wall	EU	-	F
Block	Not very comfortable	PC	-	F
Block	Limited arm space—cannot get very top or bottom	EU	-	F
PC	Wasn't as uncomfortable as the others	PC	-	F
PC	It was more efficient	PP	+	F
Pole	The pole sander was the most uncomfortable	PC	-	F
Pole	It was hard to apply pressure so the job took longer	PC	-	F
Pole	It was difficult to use the device when there were lots of bumps b/c it felt like it wanted to flip up	EU	-	F
PC	The device was very heavy to be holding up with arms for any period of time especially considering the repetition	PC	-	F
Wet	This method was easy to use	EU	-	F
Wet	But is definitely not a quick method	PP	-	F
Wet	I would not recommend this method for large areas that need sanding	PP	-	F
Block	This hand sander was easier to use than the one on the stick c/ it was able to directly apply pressure to the areas that needed the extra force	EU	-	F
PC	The vacuum sander was chosen as the best because it	PP	+	F

	got the job done the quickest			
PC	After using the other techniques, it did not require a lot of strain	PC	+	F
Pole	Was chosen as the worst b/c it was the most awkward to use.	EU	-	F
Pole	The end constantly wanted to flip over.	EU	-	F
Pole	It was harder to apply pressure using this method	EU	-	F
Pole	This was hard to use b/e the head of the device would rotate, even when you didn't want it to. It made it difficult to hold against the wall.	EU	-	F
Pole	However, it was lightweight and the handle decreased the amount of pressure you needed to apply	EU	+	F
PC	This was more efficient to use	PP	+	F
PC	But it took a lot more effort to use b/c of the large size and b/c the cord got in the way.	PC	-	F
PC	It would be nice for bigger jobs, but too much effort for smaller jobs	PP	+	F
Wet	Easy to use	EU	+	F
Wet	Lots of manual labor required	EU	-	F
Wet	I think this would be very time-consuming for large scale jobs to the point where it wouldn't be worth it to use this for a larger job.	PP	-	F

Block	The handle made this device easier to use than the sponge one	EU	+	F
Block	I felt like I had more control over the device	EU	+	F
Block	and I felt like it was very effective at getting the job done.	PP	+	F
Block	It required less force than the wet method	EU	-	F
Block	The tool was light weight	PC	+	F
Block	It seemed more effective than any except the vacuum sander	EU	+	F
Pole	The tool was too hard to manipulate	EU	-	F
Pole	The only good thing about it was that it didn't require much force	PC	+	F
Pole	I didn't feel it was very effective either	EU	-	F
Pole	It was very effective for hard to reach places	EU	+	F
Pole	It was actually pretty hard for close areas b/c of the longer pole	EU	-	F
PC	The machine was extremely heavy	PC	-	F
PC	I would've definitely taken a break in real life	PC	-	F
PC	It was too big	EU	-	F
PC	I was working form far away and couldn't really see what I was doing	EU	-	F
Wet	In general I don't know if I did it correctly	EL	-	F
Wet	I didn't know what was the correct amount of water	EL	-	F

	needed and when I had to re-dampen it.			
Wet	It was harder than the first one because it wasn't as strong.	EU	-	F
Wet	Got mud all over my hands because of the water	EU	-	F
Block	It gets your arm pretty tired pretty quickly for high areas	PC	-	F
Block	I felt like I had good control over what I was doing	EU	+	F
Block	I could see clearly how I was doing	EU	+	F
Block	It wasn't heavy	PC	+	F
Block	It worked well	EU	+	F
Block	I didn't have to apply pressure	PC	+	F
Block	It worked quickly	PP	+	F
PC	Too heavy	PC	-	F
PC	I couldn't see what I was doing	EU	-	F
PC	It also required more equipment plus ear phones	PC	-	F
PC	It was really loud	PC	-	F
Pole	It was hard to sand the lower half of the wall	EU	-	F
Pole	Felt like my hands were beginning to blister	PC	-	F
PC	The machine was really heavy for me	PC	-	F
PC	It did the best job	EU	+	F
PC	Generated the least dust	NOT CODED		F
PC	Too cumbersome for my small frame	PC	-	F

Wet	This was definitely the easiest method	EU	+	F
Wet	I got dustier than with others	PC	+	F
Wet	I couldn’t reach the top of the wall	EU	-	F
Wet	I didn’t need to apply as much pressure as with the others	PC	+	F
Block	I couldn’t reach the top of the wall	EU	-	F
Block	This was easier b/c of the angle in which I applied the pressure	EU	+	F
Block	Dustier	PC	-	F
Wet	Required the least amount of force	PC	+	F
Wet	Less stress on my hands and arms	PC	+	F
PC	Uncomfortable to use b/c it was so big and heavy	PC	-	F
Pole	This technology required a lot of upper body strength and repetitiousness	PC	-	F
Pole	Results were note seen as clearly or quickly	EU	-	F
Pole	And I felt like I wasn’t being as productive	PP	-	F
Pole	It also got dust everywhere	NOT CODED		F
PC	It tok me a little while to figure out what this technology was supposed to do	EL	-	F
PC	It was a slow process	PP	-	F
PC	Yet effective	EU	+	F
PC	My arms got tired of holdin the machine up	PC	-	F

Wet	Once again I could only sand as tall as I am	EU	-	F
Wet	I saw no results while I was scrubbing the wall	EU	-	F
Block	This technology took much more physical effort than the previous.	PC	-	F
Block	One problem with this method is that you can only sand the height that you are	EU	-	F
Block	I could see results slowly, but steadily	PP	-	F
PC	The vacuum sander produced results that could be clearly seen – it was effective	EU	+	F
PC	It also sanded the largest amount of surface area in the time allotted	PP	+	F
Wet	Showed no results	EU	-	F
Wet	Required the most physical exertion	PC	-	F
Pole	Rowing puts blisters on hands – this pole could do the same	PC	-	F
Pole	Less awkward than vacuum thing but more work	PC	-	F
Pole	My arm cramped up	PC	-	F
Pole	I had to switch out arms a lot	PC	-	F
PC	Very large and qawkward	PC	-	F
PC	May work better on a larger space	PP	+	F
PC	Had to use a lot of force	PC	-	F
PC	Hard to sand in low areas	EU	-	F
Wet	This technique was effective	EU	+	F

Wet	But if I had to do a whole house with one I think I'd shoot myself	PP	-	F
Wet	Sanding tool needs more surface area to be effective for large jobs	PP	+	F
Block	A step up from the wet method good for the size work area allotted	PP	+	F
Block	Medium/heavy force was required	PC	-	F
Block	VERY noticeably dusty!	PC	-	F
Block	Easiest to use	EU	+	F
Block	Not awkward	PC	+	F
Wet	Very low dust	PC	+	F
Wet	Small size was not very time oriented	PP	-	F
Wet	Others were faster	PP	-	F
Wet	Others had more reach	EU	-	F
Block	Not the most effective in terms of speed	PP	-	M
Block	Most control over it	EU	+	M
Block	I felt that I could sand for a long time	PC	+	M
Block	I got the best results with this	EU	+	M
Wet	Easy to use	EU	+	M
Wet	It made the wall look like crap	EU	-	M
Wet	When it got too much sand on it, it became ineffective	EU	-	M
Pole	I felt it was the easiest	EU	+	M

Pole	And most effective	EU	+	M
Pole	It did create a lot of dust, though	NOT CODED		M
Pole	And took more effort than the vacuum	PC	-	M
Wet	The results looked bad where wet mud clumped up	EU	-	M
Wet	Smallest surface area and not practical for most projects	PP	-	M
PC	Easy to use	EU	+	M
PC	Faster	PP	+	M
PC	Much less dust	NOT CODED		M
Wet	Did not see good results	EU	+	M

Vita

Deborah E. Young received a baccalaureate in biology from Virginia Tech and a master of science degree from North Carolina State University, in ecology. After working as a professional industrial hygienist and adjunct instructor for the Grado Department of Industrial and Systems Engineering, she returned to graduate school for a second master of science degree and doctorate from Virginia Tech, in industrial engineering. She is a certified industrial hygienist, certified safety professional, and certified hazardous materials manager. Her doctoral study was funded with research grant and fellowship awards from the National Institute for Occupational Safety and Health of the National Institutes of Health. She holds membership in the American Industrial Hygiene Association, the American Conference of Governmental Industrial Hygienists, the American Society of Safety Engineers, the Human Factors and Ergonomics Society, and Alpha Pi Mu, the honor society of industrial engineering. She will be joining the faculty of Virginia Tech in August of 2007, as an assistant professor of the Myers-Lawson School of Construction and the Via Department of Civil and Environmental Engineering.