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Usability evaluation of drywall sanding tools

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ABSTRACT

A usability evaluation was performed on four drywall sanding tools and redesign specifications were developed for one, to improve the human-tool interface of the sander that provides the greatest control of drywall dust, a known respiratory health hazard. Sixteen novice participants performed simulated drywall-finishing tasks with each of the four tools: block, ventilated, pole, and wet sponge sanders. Outcome measures of interest were four usability metrics: "ease of use", "ease of learning", "perceived productivity", and "comfort". Scaled questionnaire items were analyzed by MANOVA and responses to open-ended questions were analyzed via content analysis procedures. The block sander, the current industry standard tool, performed best in usability evaluations of "ease of learning" and "ease of use". The ventilated sander, found to be most effective in dust control, performed poorly in terms of "ease of use" and "perceived comfort", but well on "perceived productivity". Findings from content analysis were employed in development of redesign recommendations. Redesign recommendations to improve comfort and ease are presented: reduce tool weight, reduce moment-arm, and improve grip design.

Relevance to industry: Ventilated sanding technology can substantially reduce worker exposure to drywall dust; however, usability problems might be preventing widespread adoption of this technology.

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1. Introduction

1.1. Drywall finishing processes and risks

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 et al., 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, 2000). Kaukiainen 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 also indicated that exposure to drywall compound dust may be a contributing factor. A Health Hazard Evaluation conducted by the National Institute for Occupational Safety and Health (NIOSH) found that respiratory symptoms are common among drywall finishers and tend to improve when workers were away from the workplace (Miller et al., 1997).

Drywall operations consist of two main tasks: wallboard installation and wall finishing (Pan et al., 2000). Wall finishing tasks, performed by drywall finishers, plasterers, or painters, are the operations with the greatest associated worker dust exposure (Miller et al., 1997). Wall finishing consists of two tasks: taping and sanding. Workers fill joints between wall-boards with joint compound, press tape into the wet compound, and smooth away excess. The joint compound is allowed to dry, the surface is sanded, and an additional coat is applied. This cycle is repeated three times. The final coat, once dry, is sanded until smooth (Pan et al., 2000). The most common sanding tool employed in the drywall-finishing industry is the hand-held block sander (Young-Corbett and Nussbaum, 2009b).

There are additional sanding methods that offer some control of worker exposure to dust from construction drywall-finishing operations: ventilated sanding, pole sanding and wet sanding. All three methods are recommended by NIOSH (2000). Ventilated 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. 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. Wet sanding is accomplished in one of two methods. In one method, the drywall compound is allowed to cure and then re-

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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. Ventilated sanding equipment has been found to produce substantially less dust than the other sanding methods (Young-Corbett and Nussbaum, 2009a).

Despite the existence of engineering and work-practice control technologies for the mitigation of this hazard, worker exposures to dust persist in the drywall-finishing industry (NIOSH, 2000). A survey of owners of drywall-finishing contracting firms revealed that ventilated sanders and wet methods are not employed by most (Young-Corbett and Nussbaum, 2009b). The work presented here is part of a larger effort to identify barriers inherent to the drywall-finishing work system that are preventing the use of highly effective and available dust control technologies. 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.

1.2. Usability

As the role of perceived usability in technology adoption has been documented in the literature (Tornatzky and Klein, 1982), one potential barrier to dust control technology adoption could be a sub-optimal human-tool interface. Therefore, a usability evaluation was undertaken to identify issues inherent to the design of the wet sponge, vacuum, and pole sanders. Indeed, some evidence exists of the need for improvement of the human-tool interface for these sanders. In a study of drywall finisher perceptions of work-related risk factors, Pan et al. (2000) found that pole sanders were associated with physical stress to the neck, shoulders, back and wrists/hands. In a survey of drywall firm owners, human-tool interface problems associated with ease-of-use, learnability and productivity were identified as barriers to the adoption of the vacuum sander and wet sponge (Young-Corbett and Nussbaum, 2009b). More generally, the National Academy of Sciences reported that there is evidence of a link between tool design factors, perceived comfort, and risk of musculoskeletal injury (NRC, 1998). Furthermore, poorly designed tool-user interfaces can contribute to an increase in accident risk, as well as musculoskeletal injury (Aghazadeh and Mital, 1987).

In the present study, a summative usability evaluation was performed to identify any tool-user interface related factors that might prevent adoption and regular use by end-users. Usability is defined as a composite of several attributes, including learnability, efficiency, memorability, error rate, and satisfaction (Hix and Hartson, 1993). Since the sanding technologies being evaluated here are hand tools, usability metrics previously designed to evaluate such tools were employed. Miller (2001) presented several guidelines for conducting usability evaluations of hand-tools, and several metrics were identified: 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 relevant study of usability of orbital sanders, a user-reaction survey was used to evaluate hand/arm discomfort, force required, productivity, and comfort (Spielholz et al., 2001). Based on the metrics established by these previous studies, and the findings of earlier investigations of barriers to adoption, the current study employed the following aspects of usability: ease of learning, ease of use, perceived productivity and comfort.

1.3. Redesign for improved usability

Results of a usability evaluation can help identify aspects of a tool's design or interface that require improvement, and inform the application of established heuristics to the redesign process. Several authors have provided comprehensive approaches to hand tool evaluation and design. A three-dimensional model that emphasized the dimensions of force, precision, and time was developed to classify and analyze work with hand tools (Sperling et al., 1993). In this model, redesign heuristics are prioritized based upon aspects of the tool and the work to be performed. Kuijt-Evers et al. (2007) established a set of comfort predictors for use in improved hand tool design. The Quality Function Deployment (QFD) design method was applied to the ergonomic design of hand-tools by Haapalainen et al. (2000). In this method, user requirements, design parameters, and impacts on ergonomic quality are major inputs into design decisions. A multi-level systems approach to construction tool and process design was proposed by Vedder and Carey (2005). Mital and Kilbom (1992) synthesized the findings of four decades of research pertaining to the ergonomic principles of hand tool design in a set of guidelines for the design and selection of tools. This set included heuristics for the design of tool grips, effective weight, trigger mechanisms, vibration characteristics, user characteristics and general considerations. Physical, physiological, and psychophysical methods of evaluating hand tools were integrated into an evaluation station approach to design in another case (Kadefors et al., 1993). These authors combine usability metrics and established ergonomic criteria into a set of evaluation heuristics, which fall into two general classes (characteristics of the tool and tool effects on operator). In developing a set of redesign recommendations for the ventilated sanding tool in the present study, the guidelines of Kadefors et al. (1993) were applied in the process of evaluating existing tool design and identifying problem areas. In developing recommendations for new design attributes, the specifications developed by Mital and Kilbom (1992) were employed as a framework for guiding design choices.

Based on current industry trends and design heuristics provided by Kadefors et al. (1993), two specific hypotheses were developed regarding the usability of the four drywall-finishing tools. First, it was expected that the block sander would perform better than the other three tools on usability metrics of "ease of use", "ease of learning", "perceived comfort", and "perceived productivity". Second, pole, ventilated, and wet sanders were anticipated to perform worse than the block sander on all usability metrics.

2. Methods

2.1. Experimental design

Participants performed a simulated drywall-finishing task in a laboratory setting, with each participant performing the task four times, once with each sanding technology (tool) of interest. Following each session, participants completed a usability questionnaire concerning the tool just used. Following the entire experimental set of four task sessions, participants completed a questionnaire that assessed tool usability. The experiment was conducted as a mixed-factor design, with one between-subjects factor (gender) and one repeated-measures factor (sanding tool type). Presentation order of the tools was balanced using a 4×4 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.

2.2. Participants

All participants were above the age of 18, had no prior experience with drywall sanding tools, and completed an informed consent procedure approved by the local Institutional Review Board. While a standard method of conducting usability testing is to use participants who most closely represent the target user population, this study intentionally 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. "Ease of learning" was one of the usability parameters of interest in this study, since a previous study by the authors had identified this as a potential barrier to technology adoption (Young-Corbett and Nussbaum, 2009a). The decision to use non-representative participants (i.e. novices) was carefully considered, and deemed appropriate because of the importance of minimizing any confounding effects arising from previous experience with or knowledge of drywall sanding technology.

2.3. Simulated drywall finishing task

A 1.2 × 1.2 m (4 × 4 foot) piece of drywall board was prepared for each 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 allowed to cure, per the manufacturer's instructions, by a trained drywall finisher. The board was attached to a wall inside a laboratory enclosure. Participants were instructed on the use of one of the four drywall sanding tools and asked to sand one strip for a five-minute period with a stated goal of removing as much of the joint compound as possible during that period.

2.4. Independent variables

Four drywall sanding tools (Fig. 1) were employed in this study: a block hand sander, a powered ventilated sander (model 7800, Porter Cable Inc., Cleveland, OH), a pole sander, and a wet sponge sander. These four tools were chosen because the block sander is the most commonly used tool in practice, while the other three have been recommended by NIOSH and the Association of Wall and Ceiling Industries (AWCI) as methods for reducing worker dust exposure. All four sanding tools had the same level of abrasiveness of the sanding surface (180 grit). Since previous work has demonstrated that dimensional incompatibility of construction tools impacts the work performance, safety, and retention of female workers (Durcharme, 1977), it was anticipated that gender differences might exist in the usability responses, and that these differences might be important considerations in design recommendations for tool improvement. Therefore, gender was included as a between-subject factor in the analyses described below.

2.5. Dependent variables

Usability was evaluated through four metrics: "ease of learning", "ease of use", "perceived productivity" and "perceived comfort". Each metric had several associated items in a questionnaire (Table 1), with a corresponding Likert-type scale (1 = strongly disagree, 5 = strongly agree). Open-ended questions solicited additional feedback. After the four sanding sessions, participants completed a 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". Additional open-ended questions asked participants to explain their "best" and "worst" choices in the "overall best" ranking.

3. Analysis

A mixed-factor MANOVA was used to identify whether there were effects of gender and tool type on the set of usability metrics, which revealed a significant multivariate effect of tool type (Wilk's lambda = 0.104, $F(42,140)$, $p < 0.0001$), but no effect of gender or the interaction. Subsequently, separate repeated-measures ANOVAs were used to identify effects of tool type on each dependent variable. Tukey's HSD were used to perform all post-hoc pairwise comparisons. 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, 2003). Codes that were both exhaustive and mutually exclusive were established for the set of open-ended responses. Codes were created that mapped back to the research questions pertaining to usability metrics. 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). Coding units were defined as sentences or groups of sentences connected on a unifying thought. Codes were assigned to responses by two independent coders with education in conducting human factors research, and who had been trained (by the first authors) on the particular coding definitions and process. Inter-rater reliability was calculated for each set of codes, using Krippendorff's alpha, with an acceptance criterion set at $\alpha \geq 0.8$.

4. Results

4.1. General

Univariate ANOVA showed significant effects of tool type 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 ($F(3, 60) = 9.39$, $p < 0.0001$). Mean scores from the ranking questions are summarized in Table 2.

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. There were no significant differences found among "easiest to use" rankings. ANOVA of the "overall best ranking" scores did reveal a significant effect of tool type ($F(3,45) = 6.007$; $p = 0.0016$). Results of statistical and content analyses are described in detail for each sanding tool type below, and a summary of the content analysis codes and findings of the open-ended user comments are provided in Table 3.

4.2. Block sander

The block sander performed well on metrics of "ease of learning", "ease of use", and in the overall ranking of the tools. Perceived productivity was the only metric in which it performed poorly. In post-hoc pair-wise comparisons, the block sander received significantly higher mean scores than those of the other three tools in response to two "ease of learning" questions: "It did not take long for me to feel like I was using it correctly "and "Anyone could learn to use this quickly". Similarly, the block sander received a significantly higher score on one "ease of use" question: "I didn't have any problems while using it". On the "perceived productivity" metric, however, the block sander, along with the pole and wet tools, performed significantly worse than the ventilated sander. In response to the usability ranking question, "which tool is the overall

Fig. 1. Sanding technologies (clockwise from top left): block hand sander, ventilated sander, pole sander, wet sponge sander.

best for the job", the ventilated sander and the block sander scores were significantly higher than those of the pole and wet sanders. Content analysis of the open-ended items found that, for the "ease of use" metric, the block sander received more positive comments than did the other three technologies, and fewest negative comments. Favorable comments pertained to the manual control of the device, maneuverability, user ability to see work area, and degree of pressure required to accomplish task. The block sander had the most positive comments about "comfort", as well. Positive comments pertained to the light-weight of the tool, the ability to control pressure needed to sand, and flexibility in hand position.

Table 1
Usability metrics and associated questionnaire items.

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.

4.3. Ventilated sander

The ventilated sander performed poorly on the metrics of "ease of learning" and "ease of use", but performed well in "perceived productivity" and in the overall tool ranking question. In post-hoc, pair-wise comparisons, the ventilated sander received significantly lower mean scores in response to two "ease of learning" questions: "It did not take long for me to feel like I was using it correctly "and "Anyone could learn to use this quickly". Similarly, the ventilated sander received a significantly lower score on one "ease of use" question: "I didn't have any problems while using it". The results of the usability "ease of learning" ranking question revealed that the ventilated sander, along with the pole and wet sanders, scored significantly lower than did the block sander. On the "perceived productivity" metric, however, the ventilated sander performed significantly better than the three other tools. Likewise, on the usability ranking question, "which tool is the overall best for the job", the ventilated sander and the block sander scores were significantly higher than those of the pole and wet sanders. The content analysis of open-ended items indicated that participants struggled with learning to use the ventilated sander in the beginning of the task. The ventilated sander also 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. Comfort-related

Table 2
Mean (SD) usability rankings by tool type (scale: 1 = best, 2 = second best, 3 = third best, 4 = worst).

Tool	"Easiest to learn"	"Easiest to use"	"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)

comments pertained to device weight; length of pole; overall size of tool; and associated discomfort of the hand, arm and shoulder. Several participants noted that it was difficult to change hand positioning during the task and that this contributed to arm fatigue. 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. A related complaint concerned tool configuration's interference with the user's 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. Comments noted that it was difficult to see the quality of the sanding performance with the current tool configuration, because of these factors. 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.

4.4. Pole sander

The pole sander performed poorly on the metrics of "ease of use" and "perceived productivity", and was significantly lower on the "best overall" rank, than the block and ventilated tools. It did not perform well on any of the usability metrics evaluated in this study. The pole sander received substantially more negative comments on these metrics than did the block or ventilated tools. Negative comments concerned difficult maneuverability and difficulty in seeing work surface. 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.

4.5. Wet sander

The wet sander performed poorly on the metrics of "ease of learning", "ease of use" and "perceived productivity", and was significantly lower on the "best overall" rank, than the block and ventilated tools. It did not perform well on any of the usability metrics evaluated in this study. The wet method negative comments pertained to problems inherent to the moisture and resultant compound texture problems. Some comments indicated that participants did not learn proper wet method technique easily. The wet method received substantially more negative comments on the "ease of use" metric than did the block or ventilated tools. With 25 comments, negative feedback on the "ease of use" of the wet method was the most commented upon category in the entire set of open-ended questions. 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.

Table 3
Number of written comments for each code and category.

Code	Category	Description	Frequency of comments											
			Block			Ventilated			Pole			Wet		
			Total	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	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

Table 4
Design specifications for ventilated drywall sanding tool.

Usability Construct	Content analysis findings	Design Heuristics (Kadefors et al. 1993)	Design recommendations (based on the guidelines of Mital and Kilbom, 1992)
Ease of Use	Awkward	Tool dimension working posture	Make pole removable or adjustable in length
	Rotation of sanding head created problems with maneuverability	Mechanical output	Oscillating sanding surface
	Long pole made it difficult to sand at head-height, or below	Tool dimension grip variability	Add adjustability to pole length; Removable pole to be used only when needed
	Could not see work area	Tool Dimension	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	Tool dimension	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	Tool dimension	Coiled, retractable hose
Perceived comfort	Too heavy	Tool weight and center of mass	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	Muscular loading	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	Grip characteristics	Change diameter of pole to accommodate twenty-fifth percentile male anthropometry
	Difficult to change hand position	Grip Variability	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	Mechanical output	Dampen vibration in sanding head; use polymeric materials; muffle vacuum

5. Discussion

The block sander, the industry standard method of sanding drywall, performed best in both the quantitative and qualitative portions of the study, in terms of ease of use, ease of learning, and perceived comfort. Despite this, the block sander offers no dust control and is thus not an optimal sanding method. Favorable usability characteristics, however, might explain the widespread use of this tool in favor of those that provide worker dust protection.

The pole sander and wet sponge method performed poorly in ease of use, ease of learning, and perceived productivity. Qualitative results indicated that the tool-user interfaces of these tools are problematic in many respects. While these tools do provide some degree of reduction of dust in the worker breathing zone (Young-Corbett and Nussbaum, 2009a), usability problems may be preventing common adoption in the industry. The pole sander is often used, for the purpose of reaching distant sanding surfaces, but is not employed as a dust reduction method.

Since the ventilated sander has been found to be the most effective at reducing worker exposure to dust (Young-Corbett and Nussbaum, 2009a), results from the current usability analysis were employed to develop a set of specifications for improved design of that tool. The findings of this summative usability evaluation indicate that problems inherent to the human-tool interface, specifically regarding comfort and ease of use, might be compromising worker adoption of this technology. Heuristics developed by Kadefors et al. (1993) and Mital and Kilbom (1992) provided the theoretical framework for the development of design specifications. The hand tool evaluation heuristics developed by Kadefors et al. (1993) fall into two general classes: characteristics of the tool and tool effects on operator. Heuristics of the first class include specific parameters for tool mass, center of gravity, dimensions, and grip characteristics. The second class includes working posture, joint angles, muscle load, and local pressure in the hand. The hand tool design heuristics, developed by Mital and Kilbom (1992), are grouped into five categories: design of grip, effective weight, design of trigger, user characteristics, and general considerations. As summarized in Table 4, major findings of the usability analysis were mapped to the Kadefors et al. (1993) heuristics in evaluating the existing interface, and then the guidelines established by Mital and Kilbom (1992) informed the subsequent identification of appropriate corrective design changes.

In evaluating the content analysis findings for the ventilated sander, four applicable Kadefors et al. (1993) evaluation heuristics emerged: tool dimension, working posture, mechanical output, and grip variability. Kadefors et al. (1993) indicated that tool dimension characteristics, such as handle configuration, type of grip, functional range of motion, and tool shape, are factors that can lead to negative impacts on the user. Comments pertaining to tool dimension characteristics included those concerning user awkwardness in holding and maneuvering the ventilated sander or in positioning the sander so that the work area could be examined. Working posture, one of the Kadefors et al. (1993) tool effects on the user, is defined as a set of several postural characteristics to be avoided. One of these is prolonged work postures that involve maximal extension of the arms. A related complaint, that the tool was too heavy to hold in place when in a lateral position, can be categorized as a center of mass problem with the current tool design. Content analysis of the ventilated sander responses indicated that the tool design was causing users to work in such extended position. Users of the ventilated sander indicated some problems associated with the tool's mechanical output. Specifically, the rotation of the sanding plane created some difficulties with task accomplishment and the noise produced by the operation of the tool. A lack of grip variability, defined by Kadefors et al. (1993) as the user's ability to change hand positions, was a noted problem by the users of the ventilated tool.

Specifications for redesign of were developed based on the findings of the usability evaluation and the heuristics established by Mital and Kilbom (1992) for the design of hand tools. These authors suggest a design for variability of hand position, balance of the tool weight about the grip axis, optimal diameter of grip between 50 and 60 mm, and maximum tool weight of 2.3 kg. Accordingly, we recommend changes to the ventilated sander's effective weight, center of mass, grip design and mechanical operation, as summarized in Table 3. As this was an experimental study performed under controlled laboratory conditions, there are limitations in its external validity and applicability to occupational settings. Therefore, future research is recommended to develop and conduct iterative usability analysis of prototypes for new configurations of this sanding technology, and to incorporate other relevant issues such as performance.

6. Conclusions

Based on the significantly better performance in terms of reducing dust concentrations in the worker breathing zone (Young-Corbett and Nussbaum, 2009a), a ventilated sander is recommended for the control of worker exposure to dust during drywall finishing operations. An evaluation of the usability of this preferred tool identified important issues pertaining to "ease of use" and "perceived comfort". Such limitations, as well as higher costs and perceived or real productivity concerns, may be limiting more widespread use of this technology. Usability issues, however, may be relatively easy to ameliorate, and should be addressed by tool manufacturers. Improved tool design could remove the usability barriers that might be preventing consistent use of this technology in the drywall finishing industry.

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