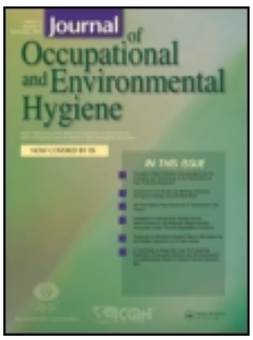

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Awwad Dababneh , Brian Lowe , Ed Krieg , Yong-Ku Kong & Thomas Waters

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Ergonomics
A Checklist for the Ergonomic Evaluation of Nonpowered Hand Tools

A checklist was developed to evaluate nonpowered hand tools for basic features related to good ergonomic tool design. The checklist contains 16 items to which a yes/no response is required. The checklist is intended to be used by tradespersons and is written in clear, simple language. This column reports on a study conducted to examine the reliability of the checklist questions in identifying the presence or absence of the basic ergonomic design features that are believed to be important for nonpowered hand tools. Using the checklist, 14 ergonomists and 126 carpenters evaluated 18 typical hand tools. Agreement among the carpenters and ergonomists was high for most of the checklist items. A few checklist questions were associated with relatively low agreement among raters in terms of the presence or absence of a design feature. Lack of agreement between raters indicates that the criterion was not explicit or that users had difficulty identifying whether the tool satisfied the particular criterion. The majority of the 18 hand tools evaluated were deemed to be lacking in multiple highly important ergonomic design features. Additional studies are being conducted to make appropriate revisions to the checklist criteria based on quantitative measures of musculoskeletal loading.

Column Editor
Scott Schneider

Reported by
Awwad Dababneh[1]
Brian Lowe[2]
Ed Krieg[2]
Yong-Ku Kong[2]
Thomas Waters[2]

[1]Department of Industrial Engineering, University of Jordan, Amman, Jordan
[2]National Institute for Occupational Safety and Health, Cincinnati, Ohio

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INTRODUCTION

Despite trends toward increased mechanization and automation, many industries and trades still use nonpowered hand tools and manual processes. A major concern in these industries is the high incidence of injuries and disabilities related to the use of hand tools. Myers and Trent[(1)] reported that occupational injuries due to hand tools resulted in approximately 433,000 emergency room visits per year, or about 12% of all reported cases from 1982 to 1986 based on the U.S. Consumer Product Safety Commission's National Electronic Injury Surveillance System. They noted that the injury rate for nonpowered hand tools was highest in the agricultural sector, followed by construction. Aghazadeh and Mital[(2)] reported that 9% of all occupational injuries occurred while using hand tools. Nonpowered hand tools are responsible for 80% of all compensable hand tool injuries.

Most hand tool-related injuries can be described as either (1) a single-incident acute trauma precipitated by a single use, or (2) cumulative trauma as a result of repeated long-term overexertion or improper use resulting in progressive damage to the arms, elbow, wrist, hand, nerves, tendons, and tendon sheaths of the fingers.[(3–5)] It is believed that these injuries can be reduced if hand tools were designed with emphasis on user comfort and good ergonomic design principles.[(6,7)]

A simple checklist was developed for the evaluation of ergonomic attributes of hand tools. The checklist addresses ergonomic attributes for all types of nonpowered hand tools. It is a product of an ongoing project at the National Institute for Occupational Safety and Health (NIOSH), the aim of which is to provide usable information about the ergonomics of hand tools to workers in the construction industry. The objective of the checklist is to provide an efficient, systematic, reliable, and easily understandable method through which construction tradespersons can verify that the tool

satisfies a basic set of ergonomic design requirements and make a selection of hand tools based on good ergonomic design principles.

This column presents the results of a study conducted to examine the reliability of the checklist items in terms of the agreement between expert raters (professional ergonomists) and the intended users of the checklist—construction tradespersons.

CHECKLIST DEVELOPMENT

The checklist was developed in the first phase of this project based on a literature review[8] and a focus group discussion among a panel of ergonomists. A group of ergonomists convened to participate in a meeting organized for the purpose of developing a set of design criteria important in an ergonomic evaluation of nonpowered hand tools. The ergonomists were all experts in relevant areas of specialization, currently leading active research programs in the areas of design, ergonomics, and safety of hand tools. In the meeting, the group came to a consensus on the ergonomic design criteria that should be included in a checklist for nonpowered hand tool evaluation. The group also discussed ergonomic design issues that were not well addressed in the literature and ways of simplifying the key information and delivering it to the typical end user of hand tools in the form of a usable checklist.

The checklist (shown in Figure 1) consists of 16 questions, of which 13 are applicable to two-handle tools (pliers, caulking gun, snips), 14 are applicable to one-handle tools other than screwdrivers (hammers, saws, utility knives), and 14 are applicable to screwdrivers. For each checklist question the tool is assessed as either satisfactory ("yes") or unsatisfactory ("no") in terms of satisfying the design feature specified by that item. Each question was assigned a weighting. The checklist score for the tool was calculated by summing all weightings for questions that received a "yes" response.

The checklist questions were divided into weighting categories with regard to their importance as judged by the panel of experts in the first phase of the project. Items of highest importance were assigned a weighting of 10 points, items of situational importance were assigned a weighting of 8 points or 4 points, and items of least importance were assigned a weighting of 2 points. The items of highest importance (10-point weighting) include those that directly affect the force used, the number of cycles needed to perform the task, or those associated with severe hazards like electrocution. The items of situational importance are important in some situations but may not be relevant in others. The items of least importance (2-point weighting) included the color of the tool, the cross-sectional shape of one-handle tools, the thermal insulation of the tool, and the ability to use the tool with either hand. These items are not important in all work situations, thus they are considered the least important items. The 16 questions are weighted so that the maximum score for a tool possessing all of the ergonomic design attributes is 100.

VALIDATION STUDY METHODOLOGY

Objectives and Hypotheses

A study was conducted to examine the reliability of the checklist and to determine relationships between checklist scores for tool attributes and the perceived comfort of use of the tool. Reliability was based on the agreement among individuals using the checklist to evaluate each hand tool. Three groups of individuals participated in the study: professional ergonomists, novice carpenters, and experienced carpenters. These individuals were asked to evaluate 18 nonpowered hand tools representative of those used in construction trades. Two methods were used to evaluate the tools: first, having the ergonomists and carpenters use the checklist to evaluate each tool, and second, rating the tool on a 5-point scale in regard to its quality, handle comfort, and comfort associated with the tool overall.

A principal hypothesis was that ergonomists' checklist evaluations and ratings of tool comfort would be consistent. The checklist item scores were hypothesized to correlate positively with ratings of comfort. A second hypothesis was that using the checklist, novice carpenters, experienced carpenters, and ergonomists would have similar evaluations of the tools. Checklist scores for the tools were hypothesized to be similar among the three groups of participants. A primary objective of the checklist was to make it clear and easily understood. Therefore, differences in ratings between tradespersons and ergonomists would indicate that this objective might not have been met. A third hypothesis was that a systematic evaluation method, such as that afforded by the checklist, would result in stronger agreement between ergonomists and tradespersons on the ergonomic design quality of the tools than would assessments based on subjective ratings of tool comfort.

Participants

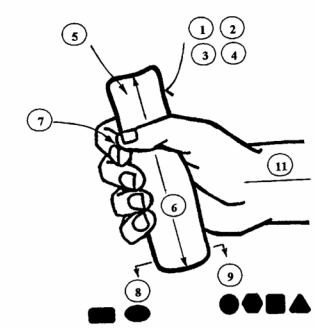
Three groups of participants were included in the study as described in Table I. Ergonomists were recruited from academic institutions with an ergonomics program of study. Experienced and novice carpenters were recruited at training workshops at the Southwest Ohio Regional Council of Carpenters. Carpenters were classified as novice if they had less than 8 years of experience in the carpentry trade and were classified as experienced if they had more than 8 years of experience in the trade. Informed consent was obtained from all study participants, and the study procedures were approved by the NIOSH Human Subjects Review Board.

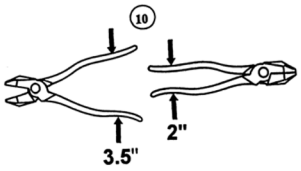
Based on responses to a brief questionnaire, novice and experienced carpenters reported that hammers, screwdrivers, measuring tapes, and utility knives were the most frequently used hand tools; snips, hammers, screwdrivers, and pliers were the most problematic tools. The checklist validation study included the evaluation of almost all of the abovementioned tools. On average, novice workers reported handling their most frequently used tools approximately 6 hours per day. Experienced carpenters reported this time as 3.5 hours per day.

Checklist for the Ergonomic Evaluation of Hand Tools

First Thing First: The Tool will do the job with the desired quality and will last as expected:
Yes: continue with the checklist;
No: reject the tool.

Considering the job the tool is designed for and the work environment, respond to each item on the checklist by "Yes," "No," or "NA" (not applicable). Place the score that corresponds to your response in the "Score" column. Add the scores of all items to get the total score of the tool. Maximum score is 100.
(*Items 7, 8, 9, and 10 are not applicable for all tools.)





Item	Ergonomic Feature	Yes	NA	No	Score
1	Grip surface is non-slippery.	+10		0	
2	Grip surface does not have sharp edges, undercuts, deep ribs, and/or finger grooves.	+10		0	
3	Grip surface is electrically insulated; tool handle is either made of wood or coated with rubber or soft plastic.	+10		0	
4	Grip surface is thermally insulated; it will not get hot or cold quickly when working in a hot or cold environment.	+2		0	
5	Handle is made of wood, or grip surface is coated with semi-pliable material; not too hard and not too soft, similar to the rubber used in the soles of sport shoes.	+10		0	
6	Grip length is 4–6"; handle does not end inside the palm of the hand.	+10		0	
7	For one-handle tools: Size of handle cross section is not too small or too large. The index finger and the thumb are allowed to overlap by 3/8" when gripping (for hammers and hammer-like tools, overlap of 1" is acceptable).	+8*	0	0	
8	For one-handle tools other than screwdrivers: Shape of handle cross section is oval or rounded-edge rectangular.	+2*	0	0	
9	For screwdrivers: The basic shape of handle cross section is circular, hexagonal, square, or triangular.	+2*	0	0	
10	For two-handle tools (plier-like): Grip span is greater or equal than 2" when fully closed and less than or equal to 3.5" when fully open.	+10*	0	0	
11	Angle of the handle is formed so that the work can be done keeping a straight wrist.	+10		0	
12	The tool weight is less than 5 lb.	+10		0	
13	The tool can be used with either hand.	+2		0	
14	The tool can be used with the worker's dominant hand.	+10		0	
15	The tool will allow a two-handed operation (using both hands at the same time).	+4		0	
16	The tool and accessories are clearly marked and/or color coded so they are easy to identify; colors are bright and tool contrasts with the surroundings of the work area.	+2		0	
	Total Score of the Tool (100 points possible)				

Measurement Scale (inches)

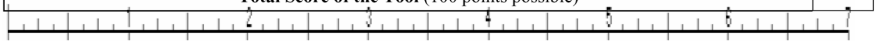


FIGURE 1. The 16-item checklist for nonpowered hand tool evaluation

Hand Tool Evaluations

Eighteen tools were selected to represent nonpowered hand tools commonly used in the construction and carpentry trades. This set of tools consisted of three hammers, three screwdrivers, two hacksaws, two wallboard saws, two utility knives, two pliers, two caulking guns, and two snips. Figure 2 shows all the tools included in the study. The tools were selected to represent a range of quality based on the checklist questions.

Participants were provided with a toolbox containing all 18 hand tools (clearly identified with labels such as Hammer I, Hammer II, etc.) and instruction materials to guide them through the evaluation of each tool. They completed the tool evaluations at their own pace, on their own time, evaluating one tool at a time, until all 18 evaluations were complete. The participants were asked to provide ratings, using a 5-point scale, for each tool in terms of its grip comfort and its overall comfort of use. Participants also assigned a rating of 1 to 5 to each tool to reflect how well the tool would do the job it was intended for and to reflect the overall quality of the tool. The 5-point scale was administered by asking the respondent how strongly he/she agreed with the statements that the tool was comfortable to use, had a comfortable grip, that the tool would do the job it was designed for, and that the overall quality of the tool was high. The scaling of the responses (1–5) was made

TABLE I. Study Participants

	Number	Age	Gender	Experience (Years)	Handedness
Novice carpenters	86	25.5	95% male	3.00 (0.25–8.00)	83% right
Experienced carpenters	40	36.7	97% male	16.02 (8.5–30.00)	81% right
Ergonomists	14	38.6	86% male	not applicable	93% right

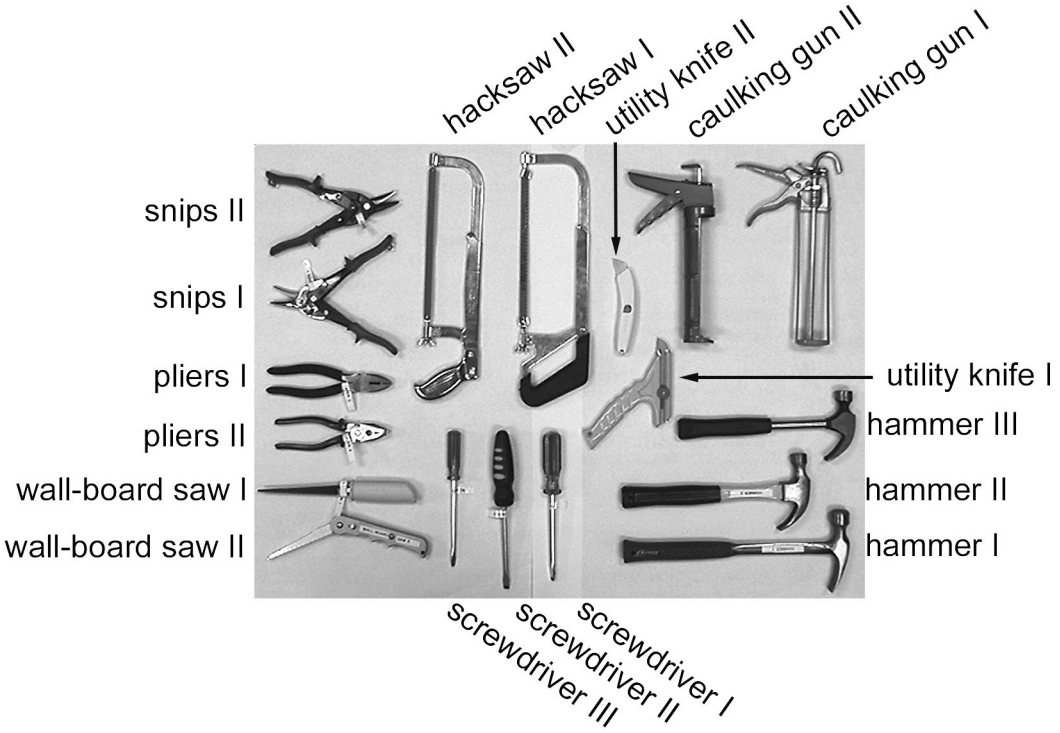


FIGURE 2. Hand tools evaluated in the study

as follows: 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, and 5 = strongly agree.

After these subjective assessments of comfort were made, the participant repeated the evaluation of each hand tool, this time using the checklist to systematically evaluate each tool based on satisfying the 16 design criteria. This required that the participant respond to all 16 checklist questions by indicating a "yes" or "no" response to each item, indicating whether the tool did or did not satisfy each design criterion.

RESULTS

Agreement Among Checklist Attributes

Participants indicated "yes" or "no" for each item on the checklist. A "yes" response meant that the tool satisfied the particular checklist criterion, and a "no" response meant that it did not. A "yes" response was scored as a 1.0 and a "no" response as 0.0. The average scores for each question for all tools and all groups of participants are listed in Table II. Agreement within each group of raters for tool/checklist items can be assessed by the percentage in the group responding in the affirmative for each tool/checklist item. A high or low percentage indicates high agreement within that group of raters that the tool did or did not satisfy the particular attribute. Percentages in the middle range (toward 50%) indicate that agreement among that group of raters was low.

A selection of 75% was chosen as a reasonable level of agreement so that question items with a percentage of affirmative responses greater than 75% or less than 25% were considered to be reliably assessed within that group of checklist users. Conversely, question items with percentages between 25% and 75% were considered to have low agreement and indicative that the question was not reliably assessed. Table II highlights the tool/checklist question combinations for which the agreement was considered to be low (i.e., a percentage agreement between 25% and 75%).

Checklist questions for which the agreement within groups of raters was low indicate that the raters were not able to reliably distinguish the presence or absence of the design feature. This may be attributed to either a lack of clarity in the way the question was phrased or because the design of the tool is difficult to assess in regard to the particular feature. For question items in which several tools exhibited low agreement within groups of raters, the question wording may be the problem. For question items in which only a few tools exhibited this low agreement within groups of raters, the tool design may have been difficult to assess.

Questions 2 ("grip surface does not have sharp edges, undercuts, or grooves") and 15 ("tool allows a two-handed operation, using both hands at the same time") exhibited the lowest agreement within groups of raters across all tools. Most of the agreement percentages were less than 75% for these question items. Question 10 ("grip span is greater than 2 inches when fully closed and less than 3.5 inches when fully opened") exhibited low agreement for two-handle tools. Questions 12, 13, and 14 ("tool weight is less than 5 lb," "tool can be used with either hand," "tool can be used with the worker's dominant hand") exhibited extremely high agreement within rater group

TABLE IIa. Average Scores by Item for One-Handle Tools

		One-Handle Tools														
Tool	**Subjects' Group**	**Q 01**	**Q 02**	**Q 03**	**Q 04**	**Q 05**	**Q 06**	**Q 07**	**Q 08**	**Q 11**	**Q 12**	**Q 13**	**Q 14**	**Q 15**	**Q 16**	**Score**
Hammer I	Novice	0.92	0.74	0.94	*0.92*	0.94	*0.92*	**0.92**	1.00	**0.68**	0.87	0.98	0.98	0.82	0.87	**88.1**
	Experienced	0.86	0.72	0.86	0.72	0.97	**0.75**	**1.00**	0.93	**0.71**	0.97	1.00	0.93	0.82	0.93	**86.1**
	Ergonomist	0.85	0.92	1.00	0.92	0.92	1.00	0.54	1.00	0.08	0.77	1.00	1.00	0.62	0.66	79.4
Hammer II	Novice	0.88	0.78	1.00	0.89	0.92	0.89	**0.93**	*1.00*	**0.66**	0.94	1.00	1.00	0.60	*0.97*	88.3
	Experienced	0.83	0.72	0.93	0.79	0.90	0.79	**0.86**	**0.89**	**0.76**	0.97	1.00	1.00	0.72	0.79	85.7
	Ergonomist	0.92	0.85	1.00	1.00	0.92	1.00	0.62	1.00	0.15	1.00	1.00	1.00	0.46	0.92	83.0
Hammer III	Novice	0.79	0.77	*1.00*	*0.89*	0.92	0.93	**0.86**	0.98	**0.61**	0.97	0.98	0.98	0.47	0.37	84.9
	Experienced	0.79	0.72	**0.86**	**0.72**	0.83	0.86	**0.79**	0.96	**0.69**	1.00	0.97	1.00	0.59	0.45	82.4
	Ergonomist	1.00	0.92	1.00	1.00	1.00	1.00	0.46	1.00	0.15	1.00	0.92	1.00	0.31	0.08	81.6
Hacksaw I	Novice	0.95	0.76	*1.00*	0.94	0.95	0.97	0.92	0.95	0.92	0.98	*1.00*	1.00	0.54	**0.50**	91.6
	Experienced	0.89	0.79	0.90	0.83	0.97	0.93	0.89	1.00	0.83	1.00	0.93	1.00	0.59	**0.69**	89.5
	Ergonomist	1.00	0.92	0.92	1.00	1.00	0.85	1.00	1.00	1.00	1.00	1.00	1.00	0.38	0.23	92.9
Hacksaw II	Novice	0.12	**0.39**	0.02	0.00	0.05	0.66	0.82	0.89	0.81	0.97	0.98	0.98	0.43	0.35	52.7
	Experienced	0.21	0.46	0.04	0.07	0.04	0.57	0.59	0.85	0.64	1.00	0.93	0.93	0.54	0.43	50.3
	Ergonomist	0.15	0.77	0.00	0.00	0.00	0.54	0.62	1.00	0.92	1.00	1.00	1.00	0.31	0.15	54.3
Wallboard	Novice	0.88	0.78	*0.98*	0.97	0.95	0.93	0.88	0.96	**0.82**	1.00	0.98	1.00	0.44	0.95	**89.9**
Saw I	Experienced	0.86	0.76	0.83	0.83	0.79	0.93	0.89	0.96	**0.79**	1.00	0.97	1.00	0.45	0.86	85.8
	Ergonomist	0.85	0.92	0.92	0.92	0.85	0.92	0.92	1.00	0.17	1.00	1.00	1.00	0.38	1.00	83.0
Wallboard	Novice	0.41	0.52	0.08	0.08	0.07	0.89	0.75	0.84	0.87	1.00	0.98	0.97	0.38	**0.44**	**60.3**
Saw II	Experienced	0.41	0.38	0.11	0.07	0.03	0.93	0.75	0.82	0.76	1.00	0.97	1.00	0.41	**0.48**	58.5
	Ergonomist	0.23	0.38	0.00	0.00	0.00	0.92	0.46	0.92	0.62	1.00	1.00	1.00	0.46	0.08	51.0
Utility Knife I	Novice	0.42	0.45	0.53	0.48	0.16	0.90	0.70	*0.86*	0.73	0.98	0.98	1.00	0.37	0.95	65.3
	Experienced	0.28	0.38	0.52	0.59	0.34	0.93	0.67	**0.60**	0.69	1.00	0.97	1.00	0.48	0.86	64.7
	Ergonomist	0.31	0.31	0.85	0.77	0.23	1.00	0.54	0.92	0.85	1.00	1.00	1.00	0.46	1.00	69.0
Utility Knife II	Novice	0.48	0.77	0.13	0.20	*0.20*	0.90	**0.84**	0.93	0.90	1.00	0.95	0.98	0.41	*0.97*	*68.1*
	Experienced	0.39	0.72	0.03	0.03	0.00	0.86	0.70	0.93	0.76	1.00	0.93	0.97	0.37	**0.79**	59.7
	Ergonomist	0.31	0.54	0.23	0.23	0.15	1.00	0.54	1.00	0.92	1.00	0.85	0.92	0.38	1.00	62.7

Note: **Bold** indicates percentages that are significantly different from ergonomists' percentages for the same item ($p < 0.05$).
Italicized underlined indicates percentages that are significantly different from experienced carpenters' percentages for the same item ($p < 0.05$).
Shaded cells represent percentages responding "yes" between 25% and 75%, indicating poor agreement (see text).

for all tools. Questions 5 and 8, relating to the handle material pliability and handle shape, exhibited high agreement for one-handle tools. Questions 3 and 4, relating to the electrical and thermal insulation of the handles, exhibited extremely high agreement for two-handle tools. Questions 3, 4, and 5 (electrical insulation of handle, thermal insulation of handle, and surface material pliability of handle) exhibited high correlation among one another confirming the similarity among the design features these questions target.

With the large sample size of this study, the binomial distribution is well approximated by a normal distribution. Analyses of variance were conducted to investigate differences in agreement between the groups of tool raters. Statistically significant differences between the groups are shown in Tables IIa–c. Most of the significant differences between ergonomists' and carpenters' evaluations were in question items 7 (for one-handle tools), 10 (two-handle tools), and 11. There were some significant differences between the evaluations of novice and experienced carpenters, but they were not consistently associated with any particular items or tools.

CHECKLIST SCORES

Overall hand tool checklist scores were calculated based on the item weightings as described in the methodology

TABLE IIb. Average Scores by Item for Screwdrivers

		Screwdrivers														
Tool	**Subjects' Group**	**Q 01**	**Q 02**	**Q 03**	**Q 04**	**Q 05**	**Q 06**	**Q 07**	**Q 09**	**Q 11**	**12**	**Q 13**	**Q 14**	**Q 15**	**16**	**Score**
Screwdriver I	Novice	0.48	**0.58**	**0.68**	0.66	0.31	**0.89**	0.80	1.00	**0.81**	1.00	0.98	0.98	0.54	0.85	**72.8**
	Experienced	0.41	0.41	**0.69**	0.59	0.31	**0.75**	0.79	0.96	**0.69**	1.00	1.00	1.00	0.48	0.86	67.7
	Ergonomist	0.54	0.23	1.00	0.77	0.08	0.50	0.69	1.00	0.25	1.00	1.00	1.00	0.31	0.69	59.7
Screwdriver II	Novice	0.89	0.70	0.98	*0.98*	0.94	*0.97*	0.98	0.90	**0.78**	0.98	0.95	1.00	0.56	*0.95*	90.0
	Experienced	0.86	0.72	0.93	**0.86**	0.90	**0.82**	0.82	0.93	**0.66**	1.00	1.00	1.00	0.55	**0.72**	84.7
	Ergonomist	1.00	0.92	1.00	1.00	1.00	1.00	0.92	0.85	0.25	1.00	1.00	1.00	0.46	0.92	88.4
Screwdriver III	Novice	0.40	0.54	**0.59**	0.57	0.33	**0.45**	**0.68**	*1.00*	**0.70**	0.98	0.98	1.00	**0.46**	0.90	**64.1**
	Experienced	0.41	0.50	**0.59**	0.45	0.17	**0.28**	**0.35**	**0.89**	**0.73**	1.00	1.00	1.00	**0.24**	0.83	56.9
	Ergonomist	0.38	0.23	0.92	0.77	0.23	0.00	0.15	1.00	0.17	1.00	1.00	1.00	0.15	0.69	48.0

section and Figure 1. Table II lists the means of the checklist scores for all tools. Analyses of variance were conducted to investigate differences between the groups of raters. Significant differences in checklist scores between the groups (carpenters and ergonomists) are also shown in Table II. There were no significant differences between the groups of subjects for 7 of the 18 tools. For 13 of the 18 tools, the maximum difference in checklist scores between rater groups did not exceed

TABLE IIc. Average Scores by Item for Two-Handle Tools

		Two-Handle Tools												
Tool	**Subjects' Group**	**Q 01**	**Q 02**	**Q 03**	**Q 04**	**Q 05**	**Q 06**	**Q 10**	**Q 11**	**Q 12**	**Q 13**	**Q 14**	**Q 15**	**Q 16**	**Score**
Pliers I	Novice	0.94	0.81	*0.97*	0.92	0.90	0.95	**0.64**	**0.75**	0.98	0.98	1.00	0.57	**0.48**	86.4
	Experienced	0.92	0.85	**0.81**	0.88	0.89	0.89	**0.69**	**0.69**	1.00	1.00	1.00	0.63	**0.52**	84.7
	Ergonomist	1.00	0.92	1.00	1.00	1.00	1.00	0.15	0.16	1.00	1.00	1.00	0.67	0.08	79.1
Pliers II	Novice	**0.45**	0.67	0.95	*0.85*	0.67	*0.93*	0.68	**0.69**	0.95	0.93	0.89	0.44	*0.79*	**75.7**
	Experienced	**0.52**	0.63	0.85	0.81	0.67	0.81	0.70	**0.63**	1.00	1.00	1.00	0.41	0.78	**74.9**
	Ergonomist	0.00	0.46	0.92	0.92	0.62	1.00	0.69	0.08	1.00	1.00	1.00	0.38	0.85	64.8
Caulking Gun I	Novice	0.33	0.63	0.05	*0.03*	0.03	0.79	0.72	0.92	1.00	1.00	1.00	0.60	*0.94*	***61.0***
	Experienced	0.21	0.59	0.00	**0.17**	0.07	0.68	0.52	0.79	0.96	0.93	0.97	0.59	**0.79**	54.0
	Ergonomist	0.31	0.38	0.00	0.00	0.00	0.54	0.50	0.85	1.00	1.00	1.00	0.46	1.00	51.6
Caulking Gun II	Novice	0.30	0.43	0.03	0.06	0.03	**0.74**	0.71	0.87	1.00	1.00	1.00	0.57	**0.42**	***56.3***
	Experienced	0.28	0.45	0.03	0.07	0.00	**0.48**	0.56	0.71	0.97	0.97	1.00	0.48	**0.48**	49.8
	Ergonomist	0.23	0.30	0.08	0.08	0.08	0.33	0.46	0.85	1.00	1.00	1.00	0.46	0.00	47.3
Snips I	Novice	0.70	0.59	0.89	0.86	0.73	**0.68**	**0.46**	**0.75**	1.00	0.83	0.97	0.44	0.74	**74.3**
	Experienced	0.66	0.62	**0.76**	0.76	0.72	**0.69**	**0.52**	0.62	1.00	0.90	0.97	0.45	0.69	72.1
	Ergonomist	0.69	0.54	1.00	0.92	0.77	0.23	0.00	0.38	1.00	0.92	0.85	0.23	0.77	60.7
Snips II	Novice	0.88	0.70	0.92	0.92	0.78	**0.84**	**0.57**	**0.78**	1.00	0.81	0.97	0.46	0.71	**81.1**
	Experienced	0.76	0.76	0.83	0.83	0.86	**0.79**	**0.60**	**0.69**	1.00	0.93	0.97	0.48	0.72	**79.5**
	Ergonomist	0.77	0.69	1.00	0.92	0.85	0.38	0.15	0.31	1.00	0.92	0.85	0.23	0.77	66.1

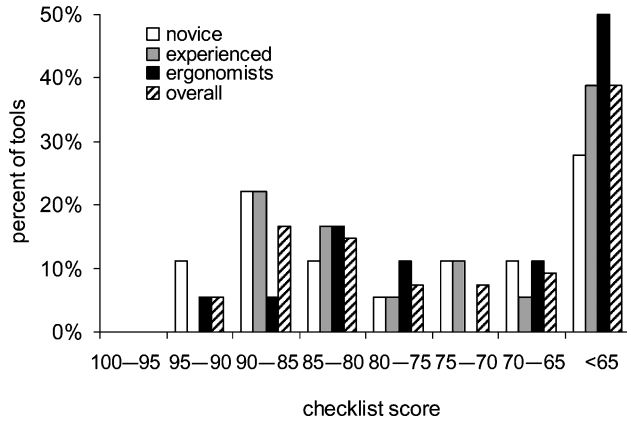


FIGURE 3. Distribution of overall checklist scores

10 points. Across all of the tools, the minimum difference in the ergonomic score among the three groups of subjects was less than 2 points for Utility Knife II, and the maximum was about 15 for Snips II. The significant differences in the overall checklist scores between the groups of raters were eliminated when the scores were recalculated with items 7, 10, and 11 excluded. This indicates that these questions reflected tool design features that ergonomists and carpenters assessed differently and that these differences had an influence on the differences in the resulting checklist scores.

The majority of the tools evaluated were deemed to be lacking in multiple ergonomic design criteria as evidenced by the distribution of checklist scores shown in Figure 3. Only 1 of the 18 tools received an average score exceeding 90 points. Eight of the 18 tools received an average score of 70 points or less. Ergonomists' evaluations of the tools tended to result in the lowest checklist scores among the three groups of participants. Evaluations by novice carpenters tended to result in the highest scores.

Ranking tools by their overall checklist score within tool category (hammer, hacksaw, wallboard saw, utility knife, screwdriver, pliers, caulking gun, snips) indicated high consistency between ergonomists and carpenters. With the exception of hammers, the rank orderings within all other types of tools were identical. Ergonomists' gave Hammer I the lowest score whereas experienced carpenters rated Hammer I with the highest score. Ergonomists and novice carpenters rated Hammer II with the highest score. Among all the tool categories the three hammers exhibited overall checklist scores that were the most similar. This explains the lack of agreement among the rater groups in terms of the rankings of hammer scores.

RATINGS OF TOOL COMFORT AND QUALITY

There were significant differences between the ergonomists and the carpenters in their ratings of tools with respect to having a comfortable grip and in their rating of overall comfort. Analyses showed that there were significant disagreements between the groups of subjects for 14 of the 18 tools. The three groups of subjects were in agreement in rating Hacksaw I, Utility Knife I, Snips I, and Pliers II. Table III shows the ratings of grip comfort and comfort of use for all of the tools and groups of raters. The largest disagreements were over Hammer I, where the difference in rating of overall comfort of use was 1.22 (on a 5-point scale) between ergonomists and experienced carpenters and 1.40 between ergonomists and novice carpenters.

Ergonomists' ratings of comfort correlated positively and significantly with most of the checklist items for all three of the tool groups (one-handle non-screwdrivers, two-handle, and screwdrivers). Table IV lists the Pearson's correlation coefficients between comfort ratings and the items on the checklist. In some cases all of the tools in the group had similar features in regard to that question item. In these cases the correlation coefficient cannot be calculated and is thus shown in the table as "tools did not vary." For one-handle tools, items 11 and 13 had weak and insignificant correlation with comfort ratings. Similarly, for the screwdriver items 4 and 16, and for the two-handle tools items 10, 13, and 16 had nonsignificant correlation coefficients.

Across all groups of subjects, the checklist score was generally significantly correlated with ratings of comfort. Table V lists the Pearson correlation coefficients between grip comfort, use comfort, quality of the tool, the ability of the tool to do the job, and the checklist score.

DISCUSSION

Questions 1 and 2, pertaining to the handle surface, resulted in relatively low agreement, particularly for two-handle tools. Question 1 on the checklist asks if the grip surface is nonslippery, and it was applicable for all tools. It was significantly correlated with the comfort ratings for all tools. Moreover, ergonomists had strong agreement in evaluating one-handle tools with regards to Question 1. Hammers I, II, and III, Hacksaw I, Wallboard Saw I, Screwdriver II, and Pliers I had grip surfaces that were coated with rubber, and all were rated nonslippery by most ergonomists (85–100%). Hacksaw II, Wallboard Saw II, Utility Knife I, and Caulking Gun I and II had metallic handles and were rated as slippery by most ergonomists (70–85%). Utility Knife II and Pliers II had a smooth and hard plastic grip surface and were rated as slippery by most ergonomists (70–100%). Snips I and II had thin plastic sleeves over metallic handles and were rated nonslippery by about 70% of the ergonomists.

Question 3 pertains to the electrical insulation of the tool and was applicable for all the groups of tools. For the one-handle tools, Question 3 was positively correlated with comfort and there was good agreement among all groups of raters in which the tool was or was not electrically insulated. Ergonomists rated all tools that had a plastic or rubber coated grip as electrically insulated, and all tools with metal handles as uninsulated. They rated all of the screwdrivers and the two-handle tools as electrically insulated.

TABLE III. Differences in Comfort Ratings of Tools Among Groups of Subjects

One-Handle Non-Screwdrivers	Group	Hammer I	Hammer II	Hammer III	Hacksaw I	Hacksaw II	Wallboard Saw I	Wallboard Saw II	Utility Knife I	Utility Knife II
The tool is comfortable to use.	Novice	**4.25**	**3.67**[A]	*3.21*[A]	4.29	*2.71*	**4.31**[A]	3.26	2.84	***3.85***
	Experienced	**4.07**	**3.43**	**2.78**	4.17	2.04	4.04	3.14	3.07	3.43
	Ergonomist	2.85	4.15	3.54	4.15	2.46	3.83	2.69	3.31	3.23
The tool has a comfortable grip.	Novice	**4.39**	3.70	3.25	4.31	*2.34*[A]	4.27	**3.19**	2.87	**3.77**
	Experienced	**4.32**	3.57	2.96	4.32	**1.93**[A]	4.00	**3.21**	2.81	3.46
	Ergonomist	3.54	3.77	3.31	4.23	2.54	4.33	2.38	3.00	3.07

Screwdrivers	Group	Screwdriver I	Screwdriver II	Screwdriver III
The tool is comfortable to use.	Novice	***3.92***[A]	3.98	***3.31***
	Experienced	3.55	4.07	2.46
	Ergonomist	3.15	4.38	2.23
The tool has a comfortable grip.	Novice	**3.69**	**4.05**	***3.06***
	Experienced	3.48	**4.07**[A]	2.32
	Ergonomist	3.00	4.62	2.08

Two-Handle	Group	Pliers I	Pliers II	Caulking Gun I	Caulking Gun II	Snips I	Snips II
The tool is comfortable to use.	Novice	3.85	2.70	3.71	**3.52**	*3.07*	3.78
	Experienced	3.50	2.42	3.82	**2.56**	2.54	3.44
	Ergonomist	3.31	2.69	3.31	2.92	3.08	3.38
The tool has a comfortable grip.	Novice	**3.95**[A]	2.61	**3.61**[A]	**3.39**	*3.17*	**3.73**
	Experienced	3.69	2.27	**3.64**[A]	**2.41**	2.57	3.44
	Ergonomist	3.75	2.54	3.00	2.77	2.77	3.23

Notes: Ratings are on a five-point scale: 1 = strongly disagree and 5 = strongly agree.
Bold ratings are significantly different from the ergonomists' ratings at $p < 0.05$.
Italicized underlined ratings are different from the experienced workers' ratings at $p < 0.05$.
[A]Differences are significant at $p < 0.01$.

TABLE IV. Pearson's Correlation Factors Between Comfort Ratings and Checklist Items

	One-Handle Tools (Non-Screwdrivers)		Screwdrivers		Two-Handle Tools (Plier-Like)	
Checklist Items	**USE Comfort**	**GRIP Comfort**	**USE Comfort**	**GRIP Comfort**	**USE Comfort**	**GRIP Comfort**
1. Nonslippery	0.332	0.405	0.353	0.346	0.361	0.474
2. No sharp edges	0.200	0.219	0.510	0.520	0.243	0.236
3. Electrically insulated	0.440	0.459	Tools did not vary		Tools did not vary	
4. Thermally insulated	0.445	0.496	**0.095**	**0.133**		
5. Rubber or wood handle	0.372	0.450	0.614	0.654		
6. Grip length	0.210	**0.173**	0.721	0.737	**0.172**	0.308
7. Grip size	0.291	0.435	0.595	0.685		
8. Handle cross section I	Tools did not vary					
9. Handle cross section II			Tools did not vary			
10. Grip span					**−0.083**	**−0.093**
11. Handle orientation	**0.057**	**−0.102**	Tools did not vary		Tools did not vary	
12. Weight <5 lbs	Tools did not vary					
13. Fit either hand	**0.003**	**0.053**			**0.020**	**−0.082**
14. Fit dominant hand	Tools did not vary			Tools did not vary		
15. Two-handed operation	0.275	0.265	**0.238**	0.360	0.339	0.242
16. Easy to identify (color)	0.289	0.346	**0.016**	**0.099**	**−0.034**	**−0.107**

Note: **Bold** coefficients are *not* significant at $p < 0.05$.

Question 4 pertains to the thermal insulation of the grip surface and was applicable for all groups of tools. For the one-handle tools, Question 4 was positively correlated with comfort ratings and was rated by ergonomists similarly to Question 3. Plastic or rubber coated grip surfaces were considered thermally insulated and tools with metal grip surfaces were not. However, for screwdrivers and two-handle tools the correlation coefficients between Question 4 and comfort were not statistically significant.

Question 5 relates to the hardness of the handle and whether the handle is coated with semipliable material or made of wood. This question was applicable for all tools. Semipliable materials and wood have good characteristics with regards to protecting the worker from impact vibration. Also, semipliable materials will allow a more even pressure distribution between the hand and the handle of the tool.[8] Question 5 was significantly correlated with the comfort ratings for one-handle tools and screwdrivers. There was a strong agreement between ergonomists and workers that tools with rubber coated grip surfaces satisfied this item. Conversely, tool handles with bare metal grip surfaces did not satisfy this item. Snips I, Snips II, and Pliers II that had handles that were coated with somewhat

TABLE V. Pearson Correlation Coefficients Among Five Characteristics of Tools

		Do the Job	Comfortable to Use	Comfortable Grip	Good Quality
Comfortable to use	Novice	0.71			
	Experienced	0.74			
	Ergonomists	0.53			
Comfortable grip	Novice	0.66	0.87		
	Experienced	0.72	0.92		
	Ergonomists	0.49	0.81		
Good quality	Novice	0.69	0.77	0.75	
	Experienced	0.73	0.83	0.83	
	Ergonomists	0.49	0.64	0.70	
Checklist ergonomic score	Novice	0.18	0.33	0.37	0.26
	Experienced	0.38	0.44	0.48	0.37
	Ergonomists	0.21	0.53	0.62	0.51

Note: All coefficients are significant at $p < 0.0001$.

hard plastic sleeves, had a percentage of "yes" responses of approximately 70%. This may indicate that plastic sleeves were not perceived to be as comfortable as rubber coated grip surfaces.

Question 6 (regarding the grip length) exhibited high agreement among raters for one-handle tools, and less so for screwdrivers and two-handle tools. Anecdotally, some workers commented that in some cases it was not clear how to define boundaries of the grip area, making it difficult to determine whether the grip length met the stated criteria.

Question 7 examined the cross-sectional size of the tool handle and was positively and significantly correlated with comfort ratings. It was applicable for the one-handle tools and screwdrivers only. With the exception of Hacksaw I, Wallboard Saw I, and Screwdriver II, ergonomists' evaluations of this feature exhibited poor agreement. The ergonomists' agreement percentages were significantly lower than those of the carpenters in eight cases and significantly higher in four cases. Since Question 7 involves a design feature that is dependent on the size of the user's hand the lack of agreement among raters within a group could be attributed to variability in hand size among the raters. However, the lower agreement percentages for ergonomists relative to the carpenters is not likely to be attributable to hand size variation.

Questions 8 and 9, regarding handle cross-sectional shape, applied only to one-handle tools and screwdrivers, respectively, and were weighted as items of lower importance (2-point weighting). High agreement was found for all groups of raters that the tools satisfied these design criteria.

Question 10 related to the grip span of the two-handle tools. It was not correlated with ratings of comfort. Ergonomists had strong agreement for three tools and did not agree for the other three tools. There was a significant difference between the groups in their ratings for item 10 for Pliers I. While workers thought that the tool had a grip span within the range specified in Question 10, ergonomists thought otherwise. A few ergonomists commented that the tool had a closed grip span that was less than the minimum of 2 inches. Because many A-shaped pliers-like tools have curved handles, it may be necessary to revise the wording of the question so that the minimum and maximum span of the handles is referenced consistently.

Ergonomists' responses to Question 11 (handle of the tool is formed in a way to allow the work to be done keeping a straight wrist) were significantly different from those of novice and experienced carpenters. This difference was particularly evident for the hammers and screwdrivers. All versions of the screwdrivers had similar handle orientation but varied with regard to other features that may affect comfort. This was also true for hacksaws, pliers, snips, and caulking guns. Wallboard Saw II was the only tool that had an adjustable handle orientation. The user could adjust the orientation of the handle into three positions: straight, pistol, and an intermediate position. On average, 87% of novice workers, 76% of experienced workers, and 62% of ergonomists thought the adjustable handle satisfied Question 11. A few of the ergonomists commented that the adjustability feature was good, but that three handle settings were not enough to cover all work situations. In general, agreement among ergonomists in terms of the handle orientation allowing a neutral wrist posture was higher than among the carpenters. Moreover, tools that had a pistol grip scored higher than tools that had a straight handle for all groups of subjects. The lack of agreement between ergonomists and carpenters in the evaluation of handle orientation emphasized the need for revision of Question 11. A clear visual illustration of a neutral wrist posture may aid in the interpretation of the question.

Questions 12, 13, and 14, relating to the tool weight and whether the tool allows for use with either hand or the dominant hand were all associated with high agreement in the affirmative for all tools. For Question 12, a weight cut-off of 5 lb was selected based on a review by Dababneh and Waters.[8] The high agreement for Question 12 was expected since all of the tools evaluated weighed less than 5 lb. Since the vast majority of nonpowered hand tools weigh less than 5 lb, the question item could be revised to be more discriminating by setting two weight cut-off levels. Tools that are used in low force, high precision tasks should weigh less than 1 lb, whereas tools used in high force, low precision tasks should generally weigh less than 5 lb.[9]

Question 15 examines whether the tool allows for a two-hand operation and was applicable for all groups of tools. This question appeared to be the least reliable in terms of agreement among the tool evaluators. Most of the tools' average ratings for Question 15 were close to 0.5, which indicates that raters neither agreed nor disagreed as to whether the criterion was satisfied. On average, tools with shorter handles had a lower score than tools with longer handles.

The majority of tools scored below 75 on the checklist. This indicates that the tools were deemed to be lacking in multiple, highly important ergonomic design features. An interpretation of the checklist scores is proposed in Table VI. This

TABLE VI. Proposed Interpretation of Checklist Scores

Score	Interpretation	Justification
>90	Good	Tool is not lacking any highly important ergonomic design features.
75–90	Fair	Tool is lacking at least one highly important design feature but not more than two highly important design features. Tool may be lacking in multiple, situationally important design features.
<75	Poor	Tool is lacking multiple highly important design features and may also lack one or more situationally important design features.

interpretation is based on three levels of tool design quality. Tools that are not lacking in any of the highly important ergonomic design features, scoring greater than 90, are deemed to be well-designed tools. Tools that score less than 90 but greater than 75 are lacking in at least one highly important ergonomic design feature but not more than two highly important features and are deemed to be fair designs. Tools scoring below 75 are lacking in more than two highly important design features and are deemed to be poorly designed.

Ergonomists and carpenters rated comfort differently for 15 of the 18 tools in the study. Both groups of carpenters gave Hammer I a mean "use comfort" rating larger than 4, but ergonomists gave it a mean rating of 2.85. The largest differences in ratings of comfort between these groups were approximately 26% of the comfort scale range. The largest differences in checklist scores between these groups were only 15% of the checklist score range. The systematic application of the checklist methodology thus reduced the discrepancies between ergonomists and carpenters that were evident in their assessments of tool comfort.

A large contradiction in the comfort ratings between ergonomists and carpenters was also apparent for Wallboard Saw II, Screwdriver III, and Caulking Gun II. These large contradictions in the comfort ratings indicate that carpenters had a different perception of tool comfort than ergonomists. There was high agreement among the three groups of participants in the comfort ratings for three tools (Hacksaw I, Pliers II, and Utility Knife I). All groups of participants gave Hacksaw I comfort ratings above 4, agreeing that the tool had a comfortable grip and would be comfortable to use. Also, all participants gave Pliers II a score of approximately 2.5 agreeing that it did not have a comfortable grip and that it would not be comfortable to use. Among the 18 tools in the study, Hacksaw I had the highest ratings for comfort, and Pliers II had the next to lowest comfort ratings. Therefore, better agreement may be obtained for tools that receive either high or low ratings of comfort.

Correlation coefficients between comfort and individual checklist items were significantly positive for most of the items across all groups of tools. However, it was not possible to investigate the correlation coefficients for all items and for all groups of tools because of the similarities of some features within certain groups of tools. Most notable was Question 12 that asked if the tool weight was less than 5 lb. All tools in the study weighed less than 5 lb, and thus no correlation coefficients between the tools' weight and its comfort rating were calculated. Questions 8, 9, 13, and 14 also exhibited cases where there was no variability in the yes/no rating, precluding the calculation of correlation with comfort.

The checklist scores for tools correlated significantly with grip comfort, overall comfort of use, quality of the tool, and the ability of the tool to do the job. The correlation of the ergonomic score with the comfort rating was stronger than the correlation with the quality of the tool and the ability of the tool to do the job. It is important to recognize that the checklist is intended for the evaluation of ergonomically related design features of the tools. There is an implied assumption when using this checklist that the tool will enable the user to do the task within the expected time, under the given work conditions, and will last for an acceptable period. If the tool does not satisfy this condition, the tool should be rejected and there is no need for an ergonomic evaluation.

CONCLUSION

Hand tools vary in their function, mechanisms, and physical design. Most are task specific. It is impractical to establish separate guidelines for the evaluation of all types of hand tools. The checklist presented in this article addresses general ergonomic design features of nonpowered hand tools that have been deemed important to the comfort and safety of the user. The checklist was developed for use in the construction trade, but it is applicable to the evaluation of any hammer, hacksaw, wallboard saw, utility knife, screwdriver, pliers, caulking gun, or snips.

Hand tool users will benefit from a systematic method to evaluate hand tools based on their ergonomic design features. This checklist is intended to provide such a systematic method. It is intended to enable workers, independent of their experience level, to evaluate and select a nonpowered hand tool in terms of the quality of its ergonomic design.

Further research is needed in the evaluation and development of the checklist to achieve a balance between the simplicity and usability of the instrument and its precision. Our group is conducting additional research to refine the checklist criteria, provide clearer guidelines for the evaluation of hand tools, and to further the understanding of the relationships between hand tool design features and quantitative measures of upper limb physical stresses. Additional validation studies are planned to evaluate the sensitivity of the checklist as an instrument for discriminating between ergonomically well-designed and poorly designed hand tools.

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