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Ergonomic evaluation of ten single-channel pipettes

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Abstract. Repetitive pipetting is a task that is associated with work-related musculoskeletal disorders of the hand and arm.
Objective: The purpose of this study was to evaluate the usability and ergonomic performance of commercially available pipettes as determined by user ratings and objective measurements.
Participants: Participants were laboratory technicians and scientists at the Lawrence Berkeley National Laboratory with experience performing pipetting tasks.
Methods: Twenty-one experienced pipette users completed a standardized pipetting task with 5 manual and 5 electronic pipettes. After using each pipette, the user rated it for attributes of comfort and usability.
Results: Although no single pipette was rated significantly better than all of the others for every attribute tested, some significant differences were found between pipettes. The Rainin Pipet-Lite received the highest overall quality score among manual pipettes, while the Thermo Scientific Finnpipette Novus was the top-ranked electronic pipette. Features correlated with greater hand and arm comfort were lower tip ejection force, lower blowout force, and pipette balance in the hand.
Conclusions: The findings, when considered with participant comments, provide insights into desirable pipette features and emphasize the value of user testing and the importance of the interactions between task, workplace layout, and pipette design.

Keywords: Laboratory, usability testing, tool design, biotechnology

1. Introduction

Scientists and technicians who work in laboratory settings are at a risk of developing upper extremity musculoskeletal disorders from repetitive activities such as pipetting. Pipetting is the task of using a pipette to aspirate and dispense a measured volume of liquid.In prior research, Bjorksten [1] surveyed 128 female laboratory employees and found that those who spent 300 hours or more pipetting per year had an increased risk of both hand and shoulder problems. David and Buckle [2] found that people who used a manual pipette more than 220 hours per year reported significantly more hand complaints compared to those who pipetted less.

Pipetting exposes users to high finger forces both from plunger operation and tip ejection (see Fig. 1 for a labeled photograph of a pipette). Contact stresses (localized pressure) may be present from hand contact with the controls and the finger rest (if present). Although the task is often highly repetitive for the hands, it also typically requires users to adopt non-neutral, static positions for the shoulders, head, and neck. The demand for high precision during some pipetting tasks in-

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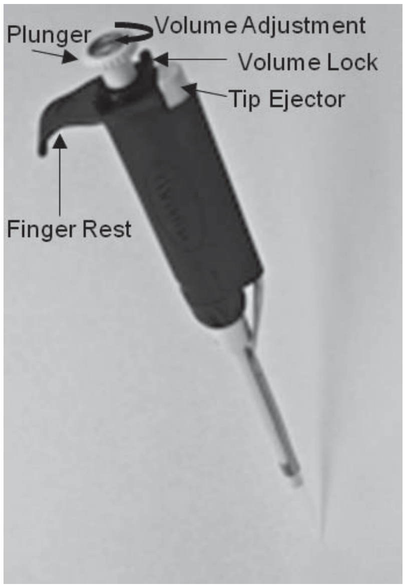

Fig. 1. Anatomy of a pipette – Rainin Pipet-Lite with LTS.

creases static muscle load [3], and increases the amount of time that the shoulder and head are held in a static posture. The workstation designs (e.g., use of pipettes in biosafety cabinets), and the overall length of most pipettes, contribute to sustained shoulder flexion (elevation of the arm in front of the body). All of these factors combine to form a task that can put scientists and technicians at risk for upper extremity, neck, and back injuries.

When evaluating the tools used for such a unique task, it is important to apply a standardized method while incorporating unique elements of the task that are common or physically demanding. The goal of this study was to compare the usability and ergonomic characteristics of commercially available manual and electronic pipettes. The approach was for experienced laboratory personnel to evaluate the usability of the pipettes with supplies and procedures that are typical of those used by many scientists and technicians.

2. Materials and methods

2.1. Participants

Participants were laboratory technicians and scientists at the Lawrence Berkeley National Laboratory (LBNL) with more than 60 hours of previous experience performing pipetting tasks. All participants provided their consent to participate in the study and did not report currently having any discomfort in their upper extremities. This study was approved by the LBNL Human Subjects Committee.

2.2. Pipette selection process

The pipettes evaluated were chosen based on the outcome of three activities. The first was a series of interviews with pipette users at LBNL to determine the most common models used. It was desirable to select some pipettes that were commonly used to allow users to have a point of reference against which they could interpret the ratings. The second was a small pilot study (N = 3) that involved rating 15 manual single-channel and 10 electronic single-channel pipettes. The third activity was based on ratings and measurements of these same pipettes by the LBNL Ergonomics Team. Based upon the results of these preliminary analyses, the most widely used and highest rated pipettes available at the time (June 2008) were chosen for this study (Table 1).

2.3. Pipette physical properties

The physical properties measured for pipettes were chosen based on interviews with users, the research team's experience in ergonomics, and previous research studies [2]. The properties measured were: pipette weight, height (from the finger rest to the end of the tip), maximum thumb reach (from the finger rest to the top of the plunger when set at the largest volume), handle girth (at the level of the middle finger), plunger force, blowout force, and tip ejection force (Table 1). The force measurements were made using a digital force gauge (Lyman, Model 7832248, Middletown, CT).

Every pipette model used in the study had a 200 μl volume capacity except for the Eppendorfs, which were not available in that volume and were tested with the 100 μl volume capacity. All models used had adjustable volume settings.

2.4. Data collection instruments

2.4.1. Participant information

After signing a consent form, each participant completed a demographic questionnaire which included pipetting experience (years) and use (hours per week). The following right hand measurements were recorded: length of digit one (thumb), hand breadth (at the level of the metacarpophalangeal joints), and overall hand length (distal wrist crease to end of middle finger). The participant's right hand lateral pinch strength was measured three times and averaged (B&L Engineering gauge, Model #PG-30).

Table 1
Physical properties of the selected pipettes

Pipette	Weight (gm)	Height (mm)	Thumb reach (mm)	Girth (mm)	Plunger force (kgf)	Blowout force (kgf)	Tip eject force (kgf)
Manual							
Biohit mLINE	79	202	30	96	0.60	2.02	2.90
Eppendorf Research	91	208	39	97	0.69	2.16	2.17
Gilson Neo	113	218	35	100	0.71	3.30	4.21
Rainin Pipet-Lite w/ LTS	108	214	34	94	0.56	1.76	0.59
VistaLab Ovation Manual	159	148	26	144	0.43	1.20	0.44
Electronic							
Biohit eLINE	167	197	0	122			0.20
Eppendorf Research Pro	207	219	20	116			1.43
Rainin EDP3-Plus	156	202	16	110			2.68
Thermo Finnpipette Novus	162	178	34	109			1.96
VistaLab Ovation Electronic	207	148	15	144			0.84

2.4.2. Pre and post quality rating questionnaire

Before starting the pipetting tasks, participants who had previous experience using any of the pipettes rated their quality. Quality was rated on a 100 mm visual analog scale (VAS) with verbal anchors (poor and excellent). The same questionnaire was also administered after all of the pipettes were evaluated. Pictures of each pipette model were provided to facilitate recognition. Since the physical styles of the pipettes varied so dramatically from one model to another, the identity of the manufacturers could not be effectively masked. However, this questionnaire enabled the experimenters to determine if the participants' opinions of various models changed during the study based on their prior experiences and biases.

2.4.3. Pipette rating sheet

After completing the pipetting task with each pipette, the participant filled out a Pipette Rating Sheet, utilizing a series of VASs to record ratings for each pipette for the following qualitative attributes: productivity, balance, accuracy of delivery, plunger comfort, grip comfort, volume adjustment, volume display, tip ejection comfort, plunger control (manual only), hand comfort, and arm comfort. The 100 mm VAS provided an unmarked linear scale with a verbal anchor at each end: 'poor' and 'excellent'. Participants were instructed to draw a vertical line between the endpoints to rate each attribute. The attributes were chosen based on interviews with users, the research team's prior experience evaluating pipettes, and previous research studies [2].

The participants were also asked to note on this sheet if they had used the pipette in the past, and if so, the duration of their use.

2.5. Task and environment

Pipettes are used in a wide variety of laboratory settings such as in biosafety cabinets, under hoods, and at open lab benches. The experimental task was carried out at a standing height (91.5 cm) open work surface to reduce the influence of other factors (e.g., chair design, hood design, etc.) Participants were allowed to adjust the location of the supplied equipment on the work surface to form a configuration that was consistent with their usual work pattern.

2.5.1. Pipette instructions

The experimenters developed a set of pipette information cards to help the participants use the pipettes that they had never seen or used before. The information card was set down in front of the participant each time they were given a new pipette model. The card showed the location of features important to the completion of the experimental task (plunger, finger rest, tip ejector, volume adjustment control). The card also contained an inset that showed a hand holding the pipette to illustrate the way the manufacturer intended the pipette to be held. An example of an information card is shown in Fig. 2.

The researcher also answered questions relevant to pipette function before the participant began the task. The participants were allowed to practice using the pipette before performing the task.

2.5.2. Pipetting task

A full pipetting cycle consisted of seven steps:

1. Acquire a new tip
2. Depress plunger in preparation to aspirate
3. Aspirate sample from a microcentrifuge tube

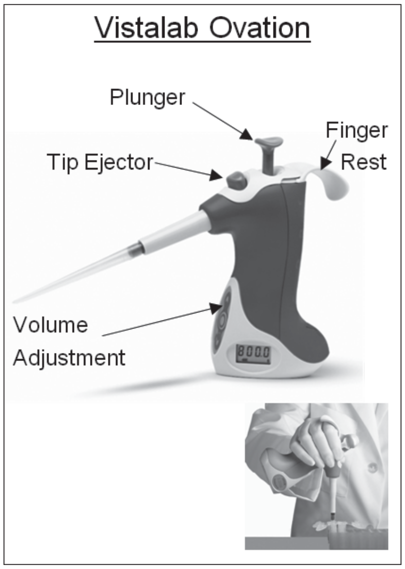

Fig. 2. Example pipette information card used during the study.

4. Depress plunger to dispense sample
5. Blowout
6. Release plunger
7. Eject tip

Participants used the pipette with their dominant hand and held the microcentrifuge tube in their non-dominant hand. Each pipetting cycle began with tip acquisition. They then aspirated a sample of water from a 2 ml microcentrifuge tube held in their non-dominant hand and dispensed it into one well of a 96-well plate. The plate was set on top of a piece of black construction paper for contrast. After dispensing the sample, they ejected the tip into a container. This was repeated 8 times until 8 wells (1 column) of the plate were filled. Each pipette was initially set to 185 μl (except for the two Eppendorf models which began at 85 μl) and after every 2 wells, the participant increased the volume of the pipette by 5 μl. This enabled them to judge the ease of volume adjustment as part of the usability evaluation. The manual pipettes were always tested before the electronic pipettes, because participants were generally more familiar with these models. Within the manual and electronic groups, the order of the pipettes was randomized.

Each trial was timed from moment the first tip was acquired to the time that the final tip was ejected.

2.6. Data analysis

Summary measures were calculated for qualitative and quantitative ratings. Ratings between pipettes were compared using repeated measures ANOVA with the Tukey follow-up test to adjust for multiple comparisons (SAS, Cary, NC). The manual and electronic pipettes were evaluated separately due to their differences in function. A p-value of 0.05 was used as the significance threshold. Associations between usability ratings, pipette physical properties, and anthropometry measures were evaluated by calculating the Pearson product-moment correlation coefficients (r).

3. Results

The mean age of the 21 participants was 38 (SD $\pm$ 14) years: 11 females (average 37 $\pm$ 13 years) and 10 males (average 40 $\pm$ 13 years). The mean experience with pipetting was 11 ($\pm$ 10) years and the mean exposure to pipettes was 7 ($\pm$ 7) hours/week. All participants were right hand dominant and their mean right hand strength was 8.8 ($\pm$ 2.1) kg. The participants' mean height was 170 ($\pm$ 10) cm. The mean measured hand length, hand breadth, and thumb length were 18.0 ($\pm$ 1.3) cm, 8.7 ($\pm$ 0.7) cm, and 6.6 ($\pm$ 0.5) cm, respectively.

3.1. Rating differences between pipettes

The mean usability, comfort, and timed productivity ratings for each pipette are presented in Table 2. Based on the Tukey tests, significant differences between pipettes, presented separately for manual and electronic pipettes, are identified in the table. For example, for the manual pipette models, tip ejection usability ratings were significantly different between the Biohit mLINE and the Rainin Pipet-Lite w/LTS.

3.2. Correlations between participant anthropometry and ratings

There were no significant correlations between the anthropometry measures (e.g., hand sizes and grip strength), or participants' pipetting experience, and the pipette usability ratings (data not shown – all correlation coefficients (r) below 0.32).

3.3. Correlations between pipette usability ratings

Hand and arm comfort were moderately to strongly correlated with pipette characteristics, such as grip

Table 2

Mean usability ratings (0 = poor; 10 = excellent) for manual and electronic pipettes [N = 21]

Pipette	Productivity	Balance	Accuracy of Delivery	Plunger Comfort	Grip Comfort	Volume Adj.	Volume Display	Tip Ejection	Plunger Control (Manual)	Hand Comfort	Arm Comfort	Cumulative Rating Score	Time (s)
Manual Models													
Biohit mLINE	6.0	7.6	8.0	6.8	6.8	4.8	7.9	5.7[a]	6.7	6.3	7.0	60.4	80.5[a]
Eppendorf Research	6.8	7.5	7.5	7.0	7.1	5.0	7.2	7.6[b]	7.8	7.1	7.3	63.4	82.5[b,c]
Gilson Neo	6.7	6.6	8.0	6.3	6.4	4.8	6.7	5.2[b,c]	6.5	6.0	6.4	57.2	71.0[a,b]
Rainin Pipet-Lite w/ LTS	7.3	7.7	8.2	7.8	7.4	5.9	7.2	8.1[a,c]	7.6	7.3	7.0	67.3	75.6[d]
VistaLab Ovation Manual	5.1	6.9	7.0	7.2	7.0	3.5	7.4	7.1	6.5	6.7	7.0	57.8	111.3[a,c,d]
Electronic Models													
Biohit eLINE	6.5	5.3[a]	6.9	5.6	4.7[a,b]	7.3[a]	7.9[a]	5.7[a,b,c]	–	5.3[a]	5.9	49.8[a]	92.4[a]
Eppendorf Research Pro	5.3[a]	5.2[b,c]	7.5	7.3[a]	6.5	5.3[b]	7.9[b]	7.9[a]	–	6.3	6.6	53.0	103.0[a,b]
Rainin EDP3-Plus	5.5[b]	6.1	7.5	5.3[a,b,c]	6.5	6.2	8.0[c]	6.7[d]	–	5.6	6.9	51.8[b]	96.7[c]
Thermo Finnpipette Novus	8.0[a,b,c]	6.8[b]	7.6	7.4[b]	7.1[a]	7.4[b,c]	8.5[d]	8.6[b,d]	–	7.1	7.2	61.4[a,b]	83.4[b,c,d]
VistaLab Ovation Electronic	5.6[c]	7.2[a,c]	7.3	7.5[c]	7.7[b]	4.5[a,c]	6.6[a,b,c,d]	7.4[c]	–	7.3[a]	7.4	53.8	98.8[d]

Significantly different ratings, within a usability column, are identified with the same superscript.
Analyses were done separately for manual and electronic pipettes.
Cumulative Score is the sum of usability ratings (e.g., from productivity to plunger control for manual pipettes).

Table 3
Correlation coefficients (r) between ratings. Statistically significant coefficients are identified in bold

	Productivity	Balance	Accuracy of Delivery	Plunger Comfort	Grip comfort	Vol. Adj.	Vol. Display	Tip Ejection	Hand Comfort	Arm Comfort
Productivity	1									
Balance	0.42	1								
Accuracy of Delivery	0.40	**0.57**	1							
Plunger Comfort	0.38	**0.61**	0.47	1						
Grip Comfort	0.41	**0.79**	**0.55**	**0.68**	1					
Vol. Adj.	**0.52**	0.21	0.32	0.29	0.25	1				
Vol. Display	0.33	0.23	0.33	0.32	0.30	**0.53**	1			
Tip Ejection	0.34	0.43	0.25	0.46	0.47	0.22	0.26	1		
Hand Comfort	0.44	**0.78**	**0.55**	**0.67**	**0.84**	0.28	0.28	**0.57**	1	
Arm Comfort	0.40	**0.72**	**0.59**	**0.57**	**0.78**	0.28	0.39	**0.51**	**0.78**	1

There were no significant correlation coefficients between ratings and time to complete task or hand anthropometry measures.

Table 4
Correlation coefficients (r) between usability ratings and physical properties of pipettes. Statistically significant coefficients are identified in bold

	Productivity	Time to do task	Balance	Accuracy	Plunger Comfort	Grip Comfort	Vol. Adj.	Vol. Display	Tip Ejection	Hand Comfort	Arm Comfort
Weight	0.41	**0.73**	**−0.63**	−0.58	0.05	−0.10	0.12	0.09	0.32	−0.08	−0.05
Height	−0.29	**−0.59**	−0.20	**0.60**	−0.25	−0.33	0.30	0.14	−0.21	−0.34	−0.46
Thumb Reach	−0.45	**−0.56**	**0.71**	**0.67**	0.51	**0.75**	−0.30	−0.19	0.27	0.60	0.50
Girth	**0.59**	**0.83**	−0.27	**−0.78**	0.08	0.02	−0.31	−0.18	0.09	0.03	0.11
Tip Eject Force	−0.15	**−0.56**	0.13	**0.58**	−0.32	0.05	−0.10	−0.05	−0.42	**−0.78**	−0.06
Plunger Force	−0.66	−0.83	−0.04	0.55	−0.60	−0.46	0.48	−0.38	−0.37	−0.27	−0.35
Blowout Force	−0.52	−0.76	−0.45	0.53	−0.76	−0.74	0.29	−0.57	−0.65	−0.58	−0.75

Some correlations (e.g., blowout force and arm comfort) are negatively correlated due to inverse relationships. Plunger and blowout force correlations were available only for the manual pipettes; due to the small sample size, none of the correlations were significant.

comfort and balance. The correlations between the subjective usability ratings of the pipettes are presented in Table 3.

3.4. *Correlations between pipette physical measures and ratings*

The correlations between the physical properties of the pipettes and the qualitative participant ratings and time to complete the pipetting task are shown in Table 4. Plunger and blowout force measures were only available for the manual pipettes (N = 5) and, due to the small sample size, none of their correlation coefficients were significant.

3.5. *Overall pipette quality ratings*

Participants were not asked to explicitly rank the pipettes; however, two summary measures were used to assess overall usability and quality. A 'cumulative rating score' was calculated from the sum of the usability ratings (Table 2). There were significant differences in the cumulative scores for electronic pipettes but not for manual pipettes. Table 5 contains the summary of quality ratings collected after all pipettes were used. The quality ratings were moderately correlated with the cumulative rating score ($r = 0.66$). The changes in quality ratings from pre-study to post-study are also summarized in Table 5 for the subset of pipettes that subjects had experience with prior to the study. The pre-post changes demonstrate that subjects altered their ratings after using the pipettes in the study. This was especially apparent with the VistaLab Ovation Electronic pipette, which had nearly a 3-point jump between pre- and post-study ratings in quality, perhaps due to the relative unfamiliarity of a design that was perceived as having some positive features.

4. Discussion and conclusions

Experienced laboratory scientists reported differences in comfort and usability for 10 commercially available pipettes. Differences between pipettes were analyzed separately for the manual (5) and electronic (5) pipettes. No pipette received the highest ratings across all usability and comfort characteristics. However, the Rainin Pipet-Lite with LTS and the Thermo Scientific Finnpipette Novus (Fig. 3) received the highest overall quality ratings and the highest cumulative

Table 5
Mean (SD) post-study quality ratings (0 = poor, 10 = excellent)

Pipette	Post quality rating[1]	Pre-post change in quality rating
Manual		
Biohit mLINE	4.7 (3.0)[c]	
Eppendorf Research	5.6 (2.7)	0.2
Gilson Neo	5.0 (3.2)[b]	−0.4
Rainin Pipet-Lite w/ LTS	7.3 (1.9)[a,b,c]	0.0
VistaLab Ovation Manual	5.1 (3.1)[a]	−0.8
Electronic		
Biohit eLINE	5.9 (2.3)[b]	
Eppendorf Research Pro	5.4 (2.6)[d]	−0.3
Rainin EDP3-Plus	5.5 (2.3)[c]	−0.8
Thermo Finnpipette Novus	7.6 (2.6)[a,b,c,d]	
VistaLab Ovation Electronic	5.9 (3.0)[a]	2.9

[1]Significantly different post quality ratings are identified with the same superscript.
Analyses were done separately for manual and electronic pipettes. Pre-post changes in quality ratings are included if four or more subjects used the pipette before the study (positive values indicate an improvement in rating after the study).

Fig. 3. Thermo Scientific Finnpipette Novus held in hand.

rating scores within the manual and electronic categories, respectively. The Rainin Pipet-Lite's design differs from its predecessors primarily with the use of lighter plunger springs and a unique tip interface that limits the force needed to apply and eject the tip. These two improvements reduce total pipetting forces by approximately 47% compared with the Rainin Classic when considering plunger, blowout, and tip ejection forces. The Thermo Scientific Finnpipette Novus was ranked higher than other electronic models across seven usability characteristics. The two pipettes show examples of recent advances in design to reduce plunger and tip ejection forces (the Rainin Pipet-Lite), to decrease reliance on the thumb (distribution of activity between the thumb and index finger), and to reduce repetitive hand activity through programmable software routines (the Thermo Scientific Finnpipette Novus).

Both the Rainin Pipet-Lite and Thermo Finnpipette Novus also received high subjective ratings for productivity. The high subjective productivity rating generally matched the objective productivity measure of least time to complete the pipetting tasks. (To control for different aspiration and dispensing speeds during the experiment, the highest speed setting was used for each electronic pipette.) However, across all subjects and pipettes, the two measures of productivity were not highly correlated ($r = -0.28$). These ratings and participant comments suggest that speed is a feature that is important to laboratory scientists. Although the Pipet-Lite was rated well for productivity, many users commented that the volume lock would slow them down and they would rather have a pipette without a lock. Other users expressed concern for loss of accuracy without a volume lock, indicating that this may be a fruitful area for design improvements. The effect of volume adjustment on productivity was highlighted by the significant ($p < 0.05$) correlation between subjective productivity and the volume adjustment usability rating ($r = 0.52$). None of the other pipette design features were correlated with subjective productivity. Higher objective productivity measures (i.e., decreased time to complete task) were related to decreased girth of the pipette handle and decreased pipette weight.

The manual VistaLab Ovation model took significantly more time to operate than the other manual models. Comments from users suggested that this was due in part to a lack of familiarity with this pipette design as well as a cumbersome volume change mechanism. It was also observed that participants accidentally ejected the tip (sometimes including the sample) into a microcentrifuge tube or plate well instead of dispensing the liquid being handled into a plate well. This confusion between the two controls suggests that more training is required for the new design of the Ovation. In addition, this design places the tip ejector at the neutral thumb position – a position that may be better suited for the plunger. The Ovation was clearly the most radical departure from linear pipette design. As Jakob Nielsen has noted, "Typically, a fresh design will be a worse design simply because it's new and thus breaks user expectations. A better strategy is to play up familiarity and build on users' existing knowledge of how a system works" [4]. On the other hand, the electronic Vistalab Ovation had a significantly higher grip comfort rating than most of the other electronic pipettes, perhaps due to a combination of design features that placed the center of gravity of the pipette under the center of the hand, reduced supination, shortened the distance between the user's hand and the pipette tip, and reduced grip force with a thicker handle [5,6].

Hand and arm comfort during pipetting were not correlated with hand size or other individual user characteristics. This suggests that specific pipette models should not be recommended to users based on their hand sizes. Hand, arm, and grip comfort were correlated with subjective measures of pipette balance, accuracy, plunger comfort, and tip ejection usability. Particularly, the high correlation with balance ($r > 0.72$), suggests that manufacturers should assess pipette balance in the hand during the design development of pipettes. Better balance was also correlated with lighter pipette weight. Hand, arm, and grip comfort were correlated with the physical properties of blowout force and tip ejection force. Both forces were negatively correlated with comfort, suggesting that they should be minimized to improve hand and arm comfort.

Although most pipettes tested were shown through user comments to have at least one positive feature, none of these pipettes emerged as a clear, universal best choice for every user. Participants stated that they favored a design that had familiar controls and that the controls could be quickly operated when needed. The importance of prior experience may have had an adverse effect on the ratings of electronic pipettes as well as both models of the VistaLab Ovation. Ergonomists and designers should consider commonly used pipette designs when developing improvements to avoid overwhelming users with radical changes. However they should also avoid the other extreme of just incrementally adding features and complexity without considering the tools, tasks, and work flow as a system. As Nielsen has noted, "Users hate change, so it's usually best to stay with a familiar design and evolve it gradually. In the long run, however, incrementalism eventually destroys cohesiveness" [4].

Limitations of this study include the use of a single task to evaluate the pipettes and the short duration of testing (less than two minutes for each participant to use each pipette). Although the task was simple enough to be generalizable to a wide range of pipetting tasks, the volume adjustment during the task was fairly frequent (three times per pipette). These frequent adjustments allowed participants to judge the adjustment mechanism, but also may have biased the ratings against pipettes with cumbersome volume adjustments. Additionally, a variation in task environment that changes participant posture (e.g., reaching up and under the sash of a biosafety cabinet to pipette) may change preferences to favor pipettes which better support those positions. The short task duration limited the amount of time that participants had to experience each model before rating it, a factor that may disadvantage new designs that participants did not have time to adjust to. Since the usage was short, users were not likely to experience hand or arm fatigue. Although participants were not given specific rest periods between trials, each trial was separated by a rating period, which lasted a couple of minutes, during which the primary task was reading. Also, the pipette order was randomized (among manual and electronic pipettes separately), eliminating an uneven contribution of fatigue to the ratings of any particular model. It would be impossible to blind users to pipette type, but the authors attempted to assess bias by asking each participant to rate each pipette for 'quality' before and after use (see Table 5). Most ratings did not change significantly, with the exception of the VistaLab Ovation Electronic, which rose almost 3 points on the 10-point scale, indicating the ability of subjects to revise their *a priori* opinion of a pipette.

Our study indicates that current pipette designs vary widely in key attributes, and these attributes contribute to the subjective grip, hand, and arm comfort of pipette users. Participant responses demonstrated that reductions in tip ejection forces as well as good pipette balance were pivotal to comfort. However, adjustments to these attributes should not radically violate user expectations or come at the cost of productivity. Based on the wealth of comments and feedback from participants, usability evaluations by experienced users seem to provide an excellent mechanism to improve function and productivity as well as address risk factors associated with work-related musculoskeletal disorders in a systematic, evolutionary process.

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