International Journal of Industrial Ergonomics 57 (2017) 63–67

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Ergonomic evaluation of an alternative tool for cake decorating

C. Harris-Adamson [a, b, *], B. Chen [c], I. Janowitz [d], D.M. Rempel [b, c]

[a] Environmental Health Sciences, School of Public Health, University of California at Berkeley, Berkeley, CA, USA
[b] Division of Occupational and Environmental Medicine, University of California at San Francisco, San Francisco, CA, USA
[c] Department of Bioengineering, University of California at Berkeley, Berkeley, CA, USA
[d] Environment Health & Safety, Lawrence Berkeley National Lab, Berkeley, CA, USA

ARTICLE INFO

Article history:
Received 8 February 2015
Received in revised form
22 August 2016
Accepted 14 November 2016

Keywords:
Cake décor
Tool
Grip force
Hand tool

ABSTRACT

Aim: Cake decorating involves several hand intensive steps with high grip force during the application of icing. The purpose of this laboratory study was to evaluate forearm muscle activity, discomfort, productivity, and usability of an alternative tool for cake decorating compared to decorating with the traditional piping bag.
Methods: Participants (n = 17) performed 2 h of cake decorating tasks using the two tools. Subjective hand and arm fatigue, usability, upper extremity posture, and muscle activity from three forearm muscles were assessed for each tool. Outcome measures were evaluated using the Wilcoxon Signed Rank test and the paired *t*-test.
Results: Less fatigue was reported in the dominant hand ($p = 0.001$), forearm ($p = 0.003$) and shoulder ($p = 0.02$) for the alternative tool when compared to the piping bag. Average median (APDF 50%) and peak (APDF 90%) muscle activity was significantly less for the alternative tool across all three forearm muscles. The alternative tool significantly reduced grip force, an important risk factor for distal upper extremity pain and disorders. Participants rated usability of the alternative tool superior for refill and comfort but the traditional method was rated better for accuracy, stability, positioning and control.
Conclusions: The alternative tool was associated with less dominant arm fatigue, muscle activity, and grip force when compared with the piping bag. However, the alternative tool did not receive the best overall usability rating due to problems with accuracy and overflow, especially with smaller decorating tips. Recommendations were made for addressing these problems with the alternative tool.

1. Introduction

The task of decorating edible items such as baked goods, candy, and ice cream cakes is a hand intensive task that is associated with high rates of hand and arm musculoskeletal disorders, including carpal tunnel syndrome (Osorio et al., 1994). Cake decorators (COC code 688 - food batchmakers) had the second highest rate of carpal tunnel syndrome of any occupation (310/100,000 workers compared to overall rate across all occupations of 36/100,000) (unpublished, Dr. Robert Harrison) and risk factor reduction is addressed in the OSHA draft guidelines for Retail Grocery Stores (OSHA, 2006). There are approximately 165,270 bakers in the U.S. in 2013 (BLS, 2013).

Workplace epidemiological studies have demonstrated an association between upper extremity musculoskeletal disorders, such as carpal tunnel syndrome, wrist tendonitis, and epicondylitis, and several biomechanical factors such as high grip or pinch force, sustained awkward wrist postures, and high repetition of hand and finger motions (NRC, 2001; Bernard, 1997). The risks are much greater when a worker is exposed to several risk factors simultaneously (Silverstein et al., 1986; Harris-Adamson et al., 2015). Reducing exposure to risk factors in jobs with high rates of distal upper extremity musculoskeletal disorders, such as cake decorating work, should reduce the severity of disability and prevent new cases.

Cake decorating traditionally involves several hand intensive steps including coating the cake with a thin layer of icing, then applying a decorative pattern of icing to the top and sides of the

Abbreviations: APDF, Amplitude Probability Distribution Function; APL, Abductor Pollicis Longus; ED, Extensor Digitorum; FDS, Flexor Digitorum Superficialis; MVC, Maximum Voluntary Contraction; RMS, Root Mean Square; RPE, Rate of Perceived Exertion.

* Corresponding author. CPE. 1301 S. 46th Street, Bldg 163, Richmond, CA 94804, USA.
E-mail address: Carisa.harris-adamson@ucsf.edu (C. Harris-Adamson).

http://dx.doi.org/10.1016/j.ergon.2016.11.004
0169-8141/

cake with a piping bag (a cloth or paper cone) filled with icing and squeezed with one hand to expel icing through a dispenser/decorative tip. The other hand typically turns the cake or holds the item being decorated. The process involves applying a high magnitude of grip force to the bag while decorating with precision. The task may require sustained awkward wrist, shoulder, and neck postures. The grip force required is influenced by a number of factors such as bag size, "stiffness" of icing (primarily a function of temperature and ingredients), and dispenser tip size.

The purpose of this laboratory study was to compare an alternative cake decorating tool to the traditional method. The alternative tool was designed to decrease the grip force and awkward postures associated with cake decorating. The study evaluated forearm muscle activity, wrist and shoulder postures, discomfort, productivity and usability among experienced cake decorators while they used each tool for 1 h.

2. Material & methodsv

2.1. Participants

Participants (N = 17) were a sample of convenience recruited from local bakeries and ice cream cake stores. Participants were required to be 18 years or older, have more than one year of experience as a paid cake decorator, and could not have any severe pain or diagnosed musculoskeletal disorder of the upper extremity. Participants completed a brief questionnaire that collected data on age, current upper body pain, and cake decorating experience. The study was approved by the University of California Committee on Human Research.

2.2. Cake decorating tools

Participants performed cake decorating using two tools, the traditional piping bag (12″ or 14″) (Fig. 1) and the alternative tool (Fig. 2). The alternative tool (Easy Piper, Dittmar Development, Coeur d'Alene, Idaho) utilized a pump to transfer icing from an 8-quart disposable bag into an elastic tube, 'charging' and inflating the tube with icing under pressure. The tube was detached from the pump then, at the other end of the tube, a hand-held applicator trigger was attached and held for dispensing icing. Participants were required to use their dominant hand to dispense the icing and could use their non-dominant hand to guide the tool. Both tools weighed approximately the same (612 g) when fully loaded with icing, however, the alternative tool could dispense 396 g of icing and the traditional piping bag could dispense 41% more (559 g). When empty, the alternative tool weighed 217 g and the traditional piping bag weighed 55 g. To compare the forces required to dispense icing from each tool, a force was applied to the piping bag (via a small block of wood to mimic palmar surface area) or the alternative tool switch using a digital force dynamometer to achieve a flow rate typical for decorating (approximately 5 g icing/6 s). Prior to testing, participants were instructed on how to refill and change the tip of the alternative tool and were allowed 30 min of practice time.

Fig. 1. Cake decorating using the traditional piping bag.

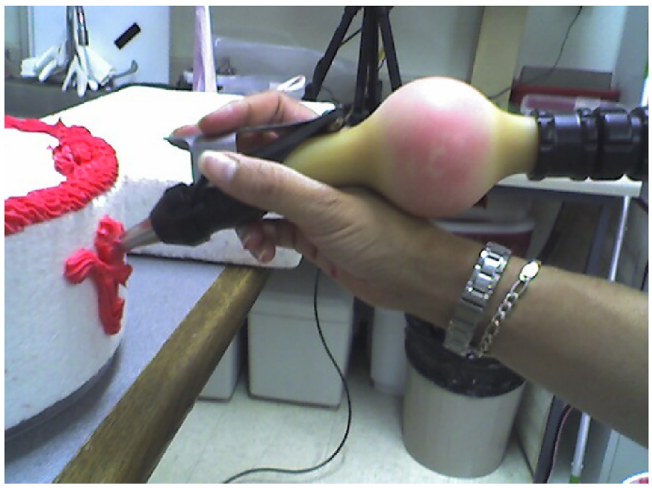

Fig. 2. Cake decorating using the alternative cake décor tool.

2.3. Tasks

Participants performed a 1-h trial of cake decorating with each tool. The order of tool testing was block randomized. Cake decorating was performed on round or rectangular Styrofoam blocks that are used for cake décor training. Two professional cake decorators, excluded from participation, identified three cake designs requiring easy (basic borders and décor), medium (swags and writing), and difficult (basket weave) decorative techniques that required a range of dispenser tips. The smallest tip was round, with a 1.5 mm diameter opening. Participants decorated in the order of easy, medium, and hard and repeated the order until 60 min had passed. The icing was a standard butter cream icing (BakeMark, Los Angeles, California) maintained at room temperature (20 °C). The work surface height was set to 88 cm but the participants could place the cake on top of a 10 cm high round Styrofoam block, if preferred. Cake decorating was done while sitting except for the basket weave and writing which were completed while standing. Participants rested for approximately 20 min between trials which served as a washout period before beginning the next condition.

2.4. Electromyography, video recording, and usability evaluation

Bipolar surface electromyography electrodes were placed over the extensor digitorum (ED), abductor pollicis longus (APL), and the flexor digitorum superficialis (FDS) muscles of the dominant forearm using recommended anatomical placement (Perotto, 2005). Circular Ag/AgCl electrodes with an active diameter of 8 mm and a center-to-center distance of 21 mm were used. Data was recorded using a 4 channel amplifier and data logger (Telemyo 2400T,

Noraxon, Scottsdale, Arizona). Raw electromyography signal was recorded at 1500 Hz. Confirmation of muscle activity was confirmed by manual resistance of each muscle, then repeated and recorded three times. Additionally, maximum grip force at five different grip spans and a maximal lateral pinch force (defined by applying a force between the thumb and radial side of the index finger) was collected (Jamar Hand Dynamometer, Hatfield, PA). Each contraction was held 3 s and repeated three times for a total of 18 trials (3 trials*5 grips spans + 3 trials*lateral pinch). The highest activity recorded for each muscle, calculated from the RMS signal using a 1 s moving window, was identified as the maximum voluntary contraction (MVC) and used to normalize subsequent values. This means that the referent MVC for different muscles could have been recorded at different hand postures (grip vs lateral pinch), but the same MVC for a given muscle was used for both devices (alternative and traditional).

Three video cameras (Pan/tilt/zoom, Vanguard) were positioned to capture subject shoulder and wrist postures; one overhead, one from the dominant side and one from front. Images from the three cameras were captured simultaneously to a computer at 30 frames per second (Quad Processor, Grand Magic Guard II) (Winters et al., 2007). Electromyography and video data were recorded over the entire 60-min trial.

At the end of the each trial, participants completed a questionnaire which assessed upper extremity fatigue in different body regions using an RPE scale (0–11), usability ratings on 11 items, preference ratings on 9 items, and recommendations for design modifications.

2.5. Data analysis

Raw electromyography data was converted to RMS using a 100 ms time constant. The signal for each muscle was normalized to percent MVC and summary measures for each trial and muscle were calculated for the amplitude probability distribution for median (APDF 50%) and peak (APDF 90%) values (Jonsson, 1982). Wrist and shoulder postures were measured by a blinded bioengineer student trained in posture assessment from a random sample of 100 (Bao et al., 2007) synced triplanar video frames per trial using MVTA software (Yen and Radwin, 2007). If joint angles could not be assessed, the frame was advanced until a measurement could be attained. All joint angle measurements were assessed to the nearest degree. Based on accuracy of measurements and consistent postures assumed by all participants, the average 50th percentile values for shoulder flexion, shoulder abduction, wrist extension, and radial deviation were calculated. Productivity was assessed by counting the number of cakes completed during each 60-min trial. Outcome measures were compared between tools using the paired *t*-test (posture) or the Wilcoxon Signed Rank test (e.g., subject ranking, APDF, productivity, fatigue). Since each person served as their own control, gender was not adjusted for in the analyses.

3. Results

The traditional piping bag required a mean force of 9.7 kg (SD = 0.52) while the alternative tool required 1.1 kg (SD = 0.11) of force to dispense icing at a rate typical for decorating (see Section 2.2).

All but one of the 17 (13 female, 4 male) subjects who participated in this study were right handed (Table 1). Across all body regions, participants reported less fatigue (Table 2) with the alternative tool than the piping bag. This difference was significant in the shoulder ($p = 0.017$), forearm ($p = 0.003$), and hand ($p = 0.001$) regions.

Participants rated usability of the alternative tool superior to the piping bag for refill, speed and comfort (Table 2). However, they rated the traditional piping bag method better for accuracy and consistency of work and rated the traditional method best overall. Open-ended comments were solicited on likes, dislikes and suggestions for improving the tool design. Recurring features that participants liked about the alternative tool were the refill method, the ease of dispensing, the ease of changing tips, and the cleanliness. Recurring dislikes for the alternative tool were overflow, air pockets in the icing, lack of control with finer décor, and weight/balance (feeling too top heavy). When using the alternative tool, especially with small tips, the icing continued to flow from the tip even after the trigger was released, leading to problems with accuracy and poor quality of work. Participants suggested that the overflow problem be addressed, the tool made lighter and better balanced, and the trigger sensitivity be improved such that icing flow stops as soon as the trigger is released. For the traditional piping bag, participants recommended improving the refill method.

Productivity was slightly improved with the alternative tool compared to the piping bag method, but the difference was not significant ($p = 0.46$).

The levels of median and peak muscle activity were less for the alternative tool than the piping bag across all muscle groups (Table 3). Posture analysis (Table 4) showed no significant difference between shoulder flexion ($p = 0.06$), shoulder abduction ($p = 0.38$) or wrist radial deviation ($p = 0.52$), however there was statistically significantly less wrist extension ($p = 0.05$) with the alternative tool.

4. Discussion

The traditional piping bag required nearly nine times the force of the alternative tool to dispense icing. However, the traditional

Table 1
Characteristics of participants. Mean (SD) N = 17.

Age (years)	46.2 (14.3)
Work experience	
Hrs/wk of work	36.2 (14.3)
Hrs/wk cake decorating	17.1 (12.8)
Years cake decorating	15.0 (9.7)
Pain level (scale 0–5) over the past 4 months	
Neck	2.6 (2.9)
Shoulders	2.8 (3.0)
Forearm	1.7 (2.1)
Wrist	3.1 (2.5)
Hand	3.2 (2.1)
Missed work days due to pain in past year	4.5 (10.2)
Number of days that pain medications were taken in past 4 months for the pain	8.7 (16.8)

Table 2
Subjective ratings of fatigue and usability for the two cake decorating tools (N = 17).

Fatigue Ratings (0–11) by Body Region	Piping Bag Mean (SD)	Alt. Tool Mean (SD)	p-value
Neck	1.11 (1.28)	0.62 (0.97)	0.08
Shoulders	1.79 (2.15)	0.89 (1.08)	0.017*
Forearms	2.63 (2.3)	0.81 (1.12)	0.003*
Hands	3.72 (2.89)	1.01 (1.28)	0.001*
Thumb	2.38 (3.13)	1.21 (1.43)	0.22
Digits 2–5	2.10 (2.98)	0.95 (1.17)	0.18

Preference	Piping Bag (n)	Alt. Tool (n)	No Prefer-ence (n)	p-value
Better set up	8	9	0	0.50
Better refill	2	15	0	0.001*
Easier tip change	4	4	9	0.63
Better accuracy	15	2	0	0.001*
Faster work speed	7	10	0	0.32
Better consistency of work	14	1	2	0.000*
speed of flow	9	8	0	0.50
Better comfort	6	10	1	0.23
Best overall	10	5	2	0.15

Usability Rating (0 = poor & 5 = excellent)	Piping Bag Mean (SD)	Alt. Tool Mean (SD)	p-value
Refill/loading icing	3.47 (1.42)	4.8 (0.39)	0.003*
Tip change	4.35 (0.93)	4.5 (0.62)	0.38
Positioning tool	4.65 (0.61)	2.82 (1.38)	0.001*
Dispensing icing	3.88 (1.22)	2.65 (1.58)	0.09
Controlling flow	4.41 (0.62)	1.71 (1.36)	0.000*
Stopping flow	4.76 (0.56)	0.88 (1.49)	0.000*
Accuracy	4.53 (0.51)	2.12 (1.36)	0.000*
Stability	4.17 (0.88)	2.82 (1.38)	0.007*
Aesthetics	3.63 (1.02)	2.53 (1.28)	0.06
Durability	3.35 (1.41)	3.59 (1.37)	0.73
Handling	3.65 (1.32)	3.00 (1.58)	0.32

Productivity	Piping Bag Mean (SD)	Alt. Tool Mean (SD)	P-value
# cakes/hr	4.17 (1.73)	4.41 (1.65)	0.46

*Significant at $p < 0.05$.

piping bag utilized a mass grip to produce a force versus the alternative tool which only utilized the 2nd digit with the remaining digits providing support of the tool. Therefore, it is important to compare the loads of each device on the 2nd digit. According to Hiroshi et al. (1995), the 2nd digit contribution to a power grip is approximately 40–45% of total static grip force. Therefore, the grip force requirement of 95 N for the traditional piping method would put a 38 N load on the second digit (40% of total force requirement). The pinch force requirement of 11 N for the alternative piping method, met entirely by the 2nd digit, represents a 71% reduction in force. The force requirements for the other digits are likely reduced even further as they are used only for stabilization while decorating using the alternative method. These findings were supported by lower peak and average muscle force across the 3 forearm muscles tested and subjective reports of less fatigue in the hand, forearm, and shoulder using the alternative cake decorating tool compared to the traditional piping bag method.

Although there was a statistically significant decrease in wrist extension when using the alternative tool, the actual difference (2.3°) was negligible and clinically irrelevant. However, the reduction in grip force is an important finding since cake decorating involves repetitive high force for sustained durations, depending on the type and number of cakes being decorated. The combination of high force, high repetition and/or high duty cycle has been shown to have a synergistic effect vs. either risk factor alone (Silverstein et al., 1986; Harris-Adamson et al., 2015). Therefore, reducing high grip force is an important strategy to reducing the overall risk of developing carpal tunnel syndrome, tenosynovitis, or other musculoskeletal disorders.

The alternative tool did not receive the best overall usability rating, primarily because of problems with overflow and accuracy. With the smaller dispenser tips, the charge used to expel the icing was too great, causing oozing of the icing even when trigger was released. These characteristics of the alternative tool compromised the precision needed to produce the intricate patterns required in

Table 3
Average median (APDF 50) and peak (APDF 90) muscle activity summary.

APDF 50: Median Muscle Activity: %MVC(SD)	Alt Tool	Piping Bag	p-value
Extensor Digitorum	50.9 (38.7)	73.1 (54.9)	0.005*
Abductor Pollicis Longus	26.7 (14.0)	36.2 (16.8)	0.004*
Flexor Digitorum Superficialis	17.6 (11.9)	24.9 (15.0)	0.0003*
APDF 90: Peak Muscle Activity: %MVC(SD)	Alt Tool	Piping Bag	p-value
Extensor Digitorum	115.5 (82.0)	184.6 (137.4)	0.006*
Abductor Pollicis Longus	60.6 (33.1)	82.3 (40.5)	0.002*
Flexor Digitorum Superficialis	41.7 (28.3)	62.8 (35.1)	0.0003*

*Significant at $p < 0.05$.

Table 4
Range of motion.

	50th% Values in degrees (SD)		
	Piping Bag	Alt. Tool	p-value
Shoulder Flexion	29.2 (9.8)	28.5 (11.5)	0.59
Shoulder Abduction	23.2 (5.3)	24.0 (3.7)	0.38
Wrist Extension	35.8 (5.1)	33.5 (4.5)	0.04
Wrist Radial Deviation	6.8 (4.7)	7.6 (5.2)	0.52

most cake decorating. In addition, the air pockets in the icing occasionally caused the icing to splatter icing on the cake with no warning, requiring the cake decorator to start the design over. Another problem identified was the heavy weight and balance of the tool. The icing was stored in an inflated rubber tube so the weight of the tool was not centered over the hand and wrist (Fig. 2); the bolus of icing tended to create an extension torque about the wrist, or supination/pronation torque about the forearm if not adequately centered. Some participants reported that this caused the alternative tool feel off-balance and more difficult to control, though this did not increase grip force or shoulder muscle utilization as indicated by the lower grip force requirements in the alternative handle, equivalent shoulder postures and reduced fatigue while using the alternative device. The participants in the present study primarily decorate elaborate cakes (for weddings and other special events) and rarely do 'production' or flat cakes. The alternative tool may have achieved better acceptance among decorators who specialize in production cakes with more simple designs.

Several limitations of the study should be acknowledged. The study was conducted in a laboratory setting without the distractions or pressure of a bakery; real work demands may increase muscle loading. Although the icing tested was a very common type of icing, there are other icings with higher viscosity (e.g., German Chocolate) that are less frequently used. Additionally, the icing tested was at room temperature. Despite best practices encouraging the use of icing at room temperature, many bakers use icing right out of the refrigerator; thus higher grip forces would be required to apply icing. Cooler icing may have reduced the overflow problem with the alternative tool, but would have increased overall grip force for the traditional method of icing. Participants had only 30 min of exposure to the alternative tool prior to testing. It is likely that more practice would have improved the productivity and usability ratings of the alternative tool. The electromyography values for some muscles were higher than expected indicating that there was either inadequate effort during the MVC or cross-talk from other muscles. Given the high forces required to expel icing (11 N of pinch and 98 N of power grip for the alternative and traditional devices, respectively), it is likely that other forearm muscles were recruited to exert such high hand exertions over such a long period of time. Given that the MVC values were only compared across tools within each participant, the results are still informative. Additionally, the MVCs for each muscle were chosen based on maximum activity measured despite the hand posture (power grip or lateral pinch) and activity for both devices were normalized to the same MVCs versus a posture specific one. This was done to provide a more direct comparison of muscle effort across devices versus a comparison of each device within a certain posture, and because of concerns that the balance of the alternative tool might require more forearm activity than a standard pinch would require. It is possible that the measuring the muscle activity of the supinator and pronator muscles may have revealed co-activation to stabilize the bolus of icing supported when using the alternative tool. These study limitations would not be expected to alter the conclusions of the study.

5. Conclusions

An alternative cake decorating tool reduced hand force and forearm muscle activity compared to the usual method and may reduce the risk of developing upper extremity pain and musculoskeletal disorders. Feedback from experienced cake decorators suggests that the design of the alternative tool be altered to address an overflow problem to improve its accuracy and associated impact on quality of work.

Acknowledgments

The study was partially funded by a cooperative grant from theNational Institute for Occupational Safety and Health.

References

Bao, S., Howard, N., Speilholz, P., Silverstein, B., 2007. Two posture analysis approaches and their application in a modified upper limb assessment evaluation. Ergonomics 50 (12), 2118–2136.
Bernard, B. (Ed.), 1997. Musculoskeletal Disorders and Workplace Factors. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health. No.97–41.
Bureau of Labor Statistics, May 2013. Occupational Employment and Wages. http://www.bls.gov/oes/current/oes513011.htm.
Harris-Adamson, C., Eisen, E.A., Kapellusch, J., Garg, A., Hegmann, K.T., Thiese, M.S., Dale, A.M., Evanoff, B., Burt, S., Bao, S., Silverstein, B., Merlino, L., Gerr, F., Rempel, D., 2015. Biomechanical risk factors for carpal tunnel syndrome: a pooled study of 2474 workers. Occup. Environ. Med. 72 (1), 33–41. http://dx.doi.org/10.1136/oemed-2014-102378.
Hiroshi, K., Satoru, K., Komei, I., 1995. Contributions and co-ordination of individual fingers in multiple finger prehension. Ergonomics 38 (6), 1212–1230. http://dx.doi.org/10.1080/00140139508925183.
Jonsson, B., 1982. Measurement and evaluation of local muscular strain in the shoulder during constrained work. J. Hum. Ergol. (Tokyo) 11 (1), 73–88.
National Research Council and Institute of Medicine, 2001. Musculoskeletal Disorders and the Workplace. National Academy Press, Washington, DC.
Osorio, A.M., Ames, R.G., Jones, J.R., Rempel, D.M., Castorina, J., Estrin, W., Thompson, D., 1994. Carpal tunnel syndrome among grocery store workers. Am. J. Ind. Med. 25, 229–245.
OSHA Draft Guidelines for Retail Grocery Stores, 2006. Ergonomics for the Prevention of Musculoskeletal Disorders. https://www.osha.gov/ergonomics/guidelines/retailgrocery/retailgrocery.html#bakery.
Perotto, A.O., 2005. Anatomical Guide for Electromyographer, fourth ed. Charles Thomas Publisher, IL.
Silverstein, B.A., Fine, L.J., Armstrong, T.J., 1986. Hand wrist cumulative trauma disorders in industry. Br. J. Ind. Med. 43, 779–784.
Winters, J., Rempel, D.M., Story, M., Lemke, M., Barr, A., Campbell, S., Danturthi, S., 2007. The mobile usability lab tool for accessibility analysis of medical devices: design strategy and use experiences. In: Winters, J.M., Story, M.F. (Eds.), Medical Instrumentation: Accessibility and Usability Considerations. CRC Press, Boca Raton, pp. 173–190.
Yen, T.Y., Radwin, R.G., 2007. Usability testing by multimedia video task analysis. In: Winters, J.M., Story, M.F. (Eds.), Medical Instrumentation: Accessibility and Usability Considerations. CRC Press, Boca Raton, pp. 159–172.