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Evaluation of two PET bottles caps: an exploratory study

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Abstract

Packaging design is a key factor on the use of the products. For packagings that require the application of biomechanical forces, some features may favor or hinder the user's ability to open them. In soft drink PET packaging, the cap features play an important role in the application of forces and perception of the activity. The aim of this study is to evaluate two models of PET bottle caps widely used in Brazil. The study variables are the torque force exertion and thermal images of the hands of the subjects before and after the attempts of opening. This study has an exploratory and experimental character and included 16 subjects of both genders. The materials include one single PET packaging model properly adapted for the purpose of the study; two cap models with different characteristics; a torque transducer; and a digital thermograph. Data was analyzed using descriptive statistics and tests for mean comparisons. The results point out that the cap design may have influenced the opening forces applied, but not the temperatures measured at the evaluated points on the subject's hands.

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Keywords: packaging; ergonomics; thermography; design; PET bottle.

1. Introduction

Handling objects is one of the major activities in the technological development of humanity. The vast majority of products we use in daily or laboral activities is, at some stage, handled by human hands. Packagings represent a great part of the interactions with everyday products. Thus, the packaging design is a key factor in issues related to the use

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of products. In packagings that require the application of biomechanical forces, some features may favor or hinder the user's ability to open them. In PET packagings for soft drinks, or PET bottles, the cap features play an important role in the application of forces and perception of the activity.

There is a growing demand for the identification and quantification of the variables involved in the interaction of human beings with packaging. Most of these interactions is through the upper limbs extremities, especially the hands. The complexity of this anatomical structure is well documented, and its importance is recognized for communication, perception and manipulation of objects in Activities of Daily Living (ADL).

The Activities of Daily Living (ADL) include those related to body care (dressing, sanitizing or feeding), known as Basic Activities of Daily Living (BADL) and Instrumental Activities of Daily Living (IADL), related to maintenance of the surrounding and interaction with the external environment, such as cleaning the house, taking care of pets, driving, using ATMs, etc. [1].

The handling tasks, particularly the palmar grips, are essential for many professional activities and also to the ADL [2]. However, palmar grips are associated with activities with extreme efforts and repetitive hand actions that contribute to the appearance of lesions and localized fatigue. Thus, the investigation of forces and constraints during grip strength is of great importance to the comprehension, prevention and rehabilitation of hand pathologies [3].

Furthermore, it is known that characteristics of the object such as its texture [4], or the curvature of the surface [5] also influence the grip forces, which can induce the subject to vary the force applied. The shape of the contact surface against the index finger influences the perception of applied force, conical surfaces lead the subject to overestimate forces, compared to flat surfaces [6]. The investigation of forces on hand interfaces is crucial to evaluate the effect of the characteristics of the handle on the grip. This knowledge can be reused to develop tool handles and prehensile activities to prevent fatigue and injuries [3].

When dealing with manual interfaces design, it is common to make comparisons between different models of a product in order to determine which provided the best use conditions. An analysis of the interaction of the hand and thumb force stress during the use of three models of laboratory pipettes indicate that the force exerted are influenced by their designs, irrespective of the task, body position and volume of sample carried. This statement has become even more strongly to the thumb forces, directly involved in the activities [7].

Another analysis involved different designs of plastic packaging for soft drinks (PET bottles) and aimed to analyze the influence of the design in the force application during attempts of opening the product and also the perception of use [8]. The results of this study demonstrated the influence of the variables such as gender, age and the design on the capacity of force exertion. Moreover, the design also influence the perceived difficulty of opening given by the subjects.

While there are many ways to evaluate a manual interface, the biomechanical requirements are the most frequently analyzed. It is common for these assessments to involve the measurement of grip forces. Generally, the muscle forces exerted during Maximum Voluntary Isometric Contraction (MVIC) are evaluated, i.e., the maximum forces that a subject is able to apply in static situations. Recent initiatives also involve analysis of pressure distribution in the hand-object interface [9, 10, 11, 12, 13]. The pressure distribution is also an important indicator since even with the application of relatively low forces, whether such forces are concentrated in a small area, become potentially harmful to the user.

Although it is possible to instrument the handle or the evaluated object to investigate interface characteristics, such as pressure concentration in certain regions of the hand, these techniques modify the characteristics of the interface. One of the most concerning interferences is the change in friction coefficient, which can induce the subject to vary the grip force applied. The sensory perception of surface, such as roughness and temperature also has an important aspect in this control. There are studies evaluating the interference caused by the use of gloves in hand-object interface. Different materials (such as rubber or cotton) and different thicknesses in an object lifting task result in smaller or higher grip forces accordingly to the thickness of the glove used [14].

That is likely due to an impairment in tactile functions, leading the participants to employ a bigger safety margin, much higher than would be required to prevent slippage of the object. The performance when lifting the object was not influenced by the variation in the thickness of the glove. However, the material caused increases in the grip strength as the time required to perform the task. Finally, the author states that the participants gained experience on the friction conditions between the glove and the object surface through the attempts.

In addition, another interesting initiative to assess the interface between hands and objects can be the thermography. This technique has been already used to analyze the variation in skin temperature through images, the thermograms. In thermography, skin temperature is measured by the infrared energy emitted by the body surface by means of instruments known as thermographs. Already in 1971 there was an initiative to evaluate the effect of the pressure applied to certain body regions, and its effect on skin temperature at these points [15].

The hands temperature is determined by complex interactions between the heat conducted from central body parts, blood perfusion into the deeper layers of the skin and heat exchange with the environment. With the advent of digital thermography one can view temperature patterns on the surface of human skin with a high degree of accuracy [16]. Still, this type of analysis reflects inter individual variations, which leads some authors to find increases or decreases in the temperature of the pressure application site.

In case of heating, this can be explained by what is known as the triple response phenomenon, in which a scratch on the skin causes a red line, due to dilatation of the capillaries. Approximately thirty seconds later, there is a peak of heat in regions around this line, possibly due to arterial dilatation. However, only the color of the skin is not necessarily indicative of its temperature, if the skin is hot and red, both capillaries and arterioles are dilated. However, if it is hot and pale, the arterioles are dilated but capillaries are not [15].

One of the implications of excessive pressure is the reduced blood flow. This reduction may decrease the local temperature and contribute to pathologies in the upper limbs, such as tendinitis and carpal tunnel syndrome. In this sense, a study involving a typing task was performed to identify variations in the temperature of the hands during and after the activity. An initial thermal image was the basis for comparisons. In a ten-minute span after the task, three images of the back of the individual's hands were captured. The results show a reduction in the temperature of the hands as the task progressed. Upon completion, the temperature of the hands went up again gradually [17].

Once detected the possibility to assess the hand-object interface with thermography, a technique that does not interfere with handle conditions, it seems reasonable to conduct a pilot study to determine its applicability. Therefore, the aim of this study was to evaluate two models of PET bottle caps widely used in Brazil with respect to the torque force exertion and the thermal images of the hand palms of the subjects before and after the interaction with the cap models during attempts of opening.

2. Material and Methods

To perform this study, a single model of PET packaging body, with 2 liters of capacity was used. This model has an internal duct in which it was coupled a torque transducer (Static Torque Screwdriver - Mecmesin Ltd.). The torque transducer was connected to an Advanced Force Gauge (AFG500 – Mecmesin Ltd.) for registering and reading of force data. Into the packaging body was alternately coupled two cap models: one with thinner and shallow grooves and a larger contact area; and one with broader and deeper grooves. In each cap, a metal socket was fixed to allow a quick coupling to the model of packaging and torque transducer. These models represent some of those evaluated in previous researches on the opening capacity [8, 18]. The assembled package design was supported on a specially constructed structure, which had a working surface at 0.85m from the floor. The figure 1 exhibits the packaging model and the caps used.

It was also used a thermograph Flir Instruments E40 (IR resolution 160x120px, MSX resolution 320x240px, sensitivity <0.07ºC, precision ±2 %, -20 to 650ºC). Such equipment was positioned on an aluminum tripod, at a height of 0,865m from the surface of a wood table to take the pictures of the user's hands. Such surface was covered with a layer of black EVA of 3mm thick. The software FLIR Tools 5.0 accompanies this device, and was used for reading the temperature of the analyzed sites. Participated in this study 16 subjects with a mean age of 36.3 years old (s.d. 9.1 years), being nine male and seven female subjects. None of the subjects related any musculoskeletal symptoms up to 12 months prior to the activities. All procedures were performed in an acclimatized room with 24ºC of temperature.

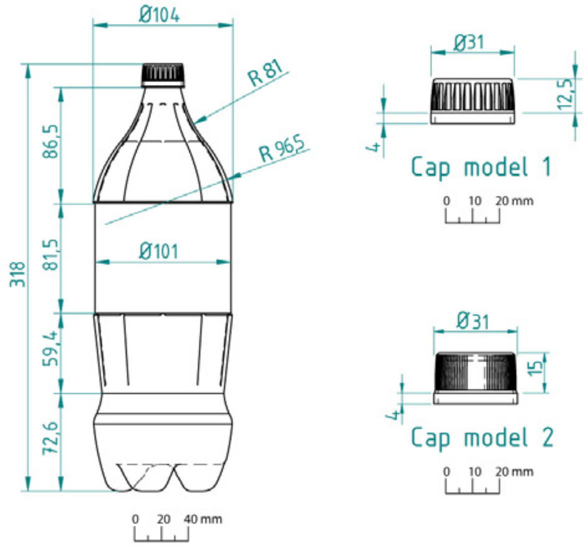

Fig. 1. PET bottle model adapted to hold a torque transducer and cap models evaluated. (Source: the author)

2.1. Procedures

All subjects signed an Informed Consent Form, in which they agreed to participate voluntarily in activities. After an explanation of the study's objectives and procedures, the subjects sat and rested the dorsal region of hands on a table so the palms of their hands were photographed with the termograph.

The subjects were then instructed to position themselves standing in front of the structure and the packaging model. The caps sequence was randomized. The subjects always held the shoulder (upper part) of the packaging with the left hand while the right one was used to make the effort on the cap. The prehension used was pulp-lateral with opposition between the thumb and the side of the middle phalanx of the index finger.

There was only one attempt for each cap, with a rest interval of 1 minute between the caps models. All forces were applied for 4 seconds, always counter-clockwise. The effect of hand dominance was not analyzed in this study. Immediately after each attempt, the subject was asked to sit again so a thermogram of his hands was captured. Therefore, at the end of the participation of each subject, three thermal images were recorded (before, after the first test and after the second test). The figure 2 exhibits a sequence of images captured for a subject.

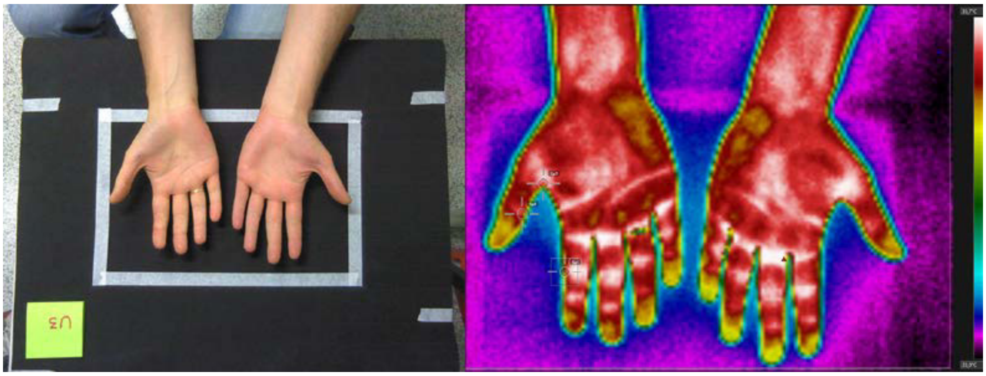

Fig. 2. Picture and thermogram of a subject's hands. (Source: the author)

2.2. Data Analysis

The obtained thermal images were analyzed with the Flir Tools 5.0 software. Three sites were inserted for temperature reading, chosen based on the areas of contact between the hand of the subject and the cap. The first site was positioned on the side of the middle phalanx of the index finger, between the proximal and distal joints. The second was placed in the palmar fold between the first and second digit. The third selected site was placed on the side aspect of the proximal joint of the thumb. The temperature was read individually at each site for each situation (before, after the first and after the second cap model), and for each subject.

Data was tabulated in a spreadsheet (Libre Office 4.2.7.2) for analysis using descriptive statistics. Later tests were performed using the statistical software OpenStat. The analysis included tests of normality (Shapiro Wilk's test) and homogeneity (Brown-Forsythe test). All data presented normality and homogeneity, which implied parametric tests (Student's t-test or one-way ANOVA with Tukey HSD *post hoc*, when applicable). Analyzes included means comparisons for two variables: torque force and temperature. For each variable were analyzed differences between trials (irrespective of the cap used) and between cap models.

3. Results

The first variable analyzed was the torque force applied by the subjects. The data analysis revealed that there were no statistically significant differences between the forces applied on the first and second opening attempts (t-test with p=0.80). The mean force applied on the first try was 1.76 N.m (median 1.60N.m – s.d. 0.43) while the second was 1.72N.m (median 1.73N.m – s.d. 0.35). This analysis does not consider the cap models, only the values of the first and second attempt.

To the forces applied in each cap model, there were significantly higher values on the cap 2 (*t*-test p=0.05). The mean force applied to the first cap model was 1.61N.m (median 1.53N.m – s.d. 0.27) while for model 2 was 1.87N.m (median 1.89N.m – s.d. 0.44). Figure 3 shows a comparative plot of applied force values in the cap models evaluated.

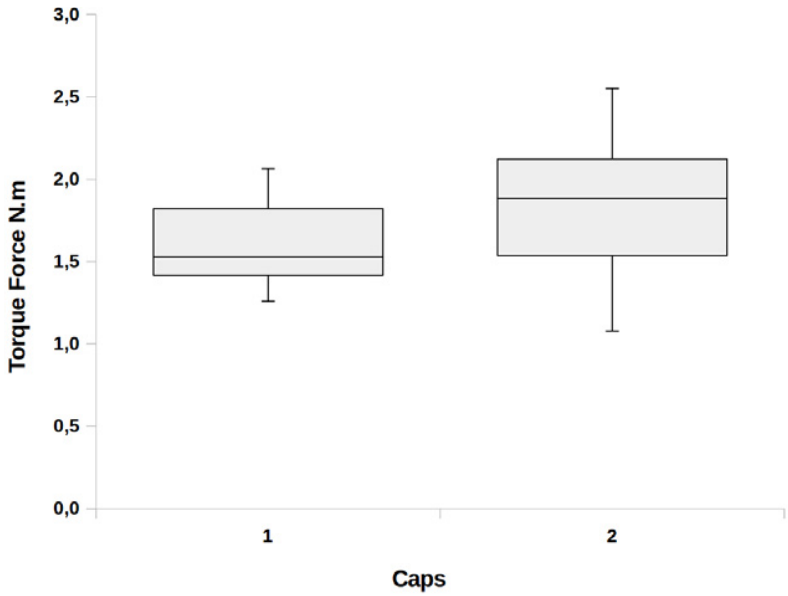

Fig. 3. Torque forces applied on cap model 1 and cap model 2. (Source: the author)

The analysis of the temperatures before and after each trial showed that the average temperature of the hand on all three sites softly dropped after the first attempt, but it increased again after the second attempt, being slightly above the original temperature for each of the three points analyzed. The analysis of the temperatures for each of the three sites of the hand indicated that, in general, the forces exerted did not cause significant variation in the temperature of the hand in the three points analyzed. This was true for the thumb site (ANOVA p=0.87), which mean temperatures were 31.3ºC (median 32.3ºC – s.d. 2.6) before the first attempt, 30.2ºC (median 31.7ºC – s.d. 2.3) after testing with the cap 1 and 32.2ºC (median 31.5ºC – s.d. 2.6) after the activity with the cap 2. Figure 4 shows a comparative plot of the temperatures measured at the thumb on the three situations of the study.

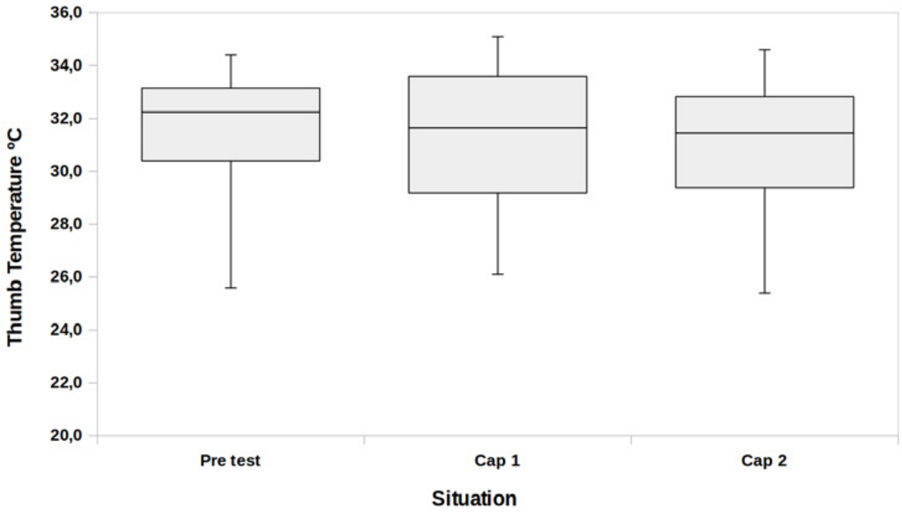

Fig. 4. Measured temperature on thumb point before the experiment, after the attempt using cap model 1 and 2. (Source: the author)

The same was observed for the palmar fold between the first and second digits (ANOVA p=0.77), which mean temperatures were 32.5ºC (median 33.3ºC – s.d.1.7) before the first attempt, 32.6ºC (median 32.8ºC - s.d. 2.1) after testing with the cap 1 and 32.1ºC (median 32.6ºC – s.d. 2.1) after testing with the cap model 2 . Figure 5 shows a comparison chart of the temperatures measured on the palmar fold site in all the three situations of the study.

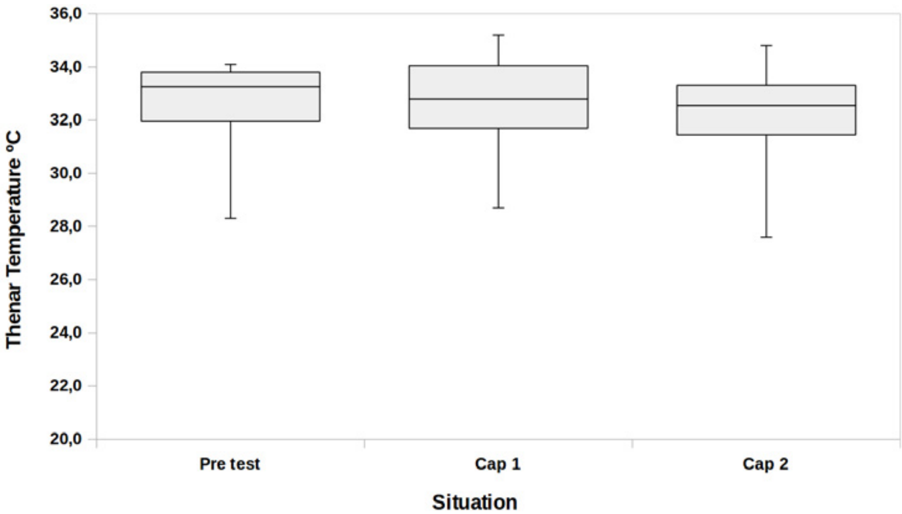

Fig. 5. Measured temperature on palmar fold site before the experiment, after the attempt using cap model 1 and 2. (Source: the author)

To the index finger site there was a similar behavior (ANOVA p=0.96). The mean temperatures were 30.3ºC (median 31.6ºC – s.d. 2.8) before the first attempt, 30.3ºC (median 30.8ºC – s.d. 3.0) after testing with the cap 1 and 30.0ºC (median 30.2ºC- s.d. 2.4) after testing with the cap 2. Figure 6 shows a comparison chart of the temperatures measured on the index finger in the three situations of the study.

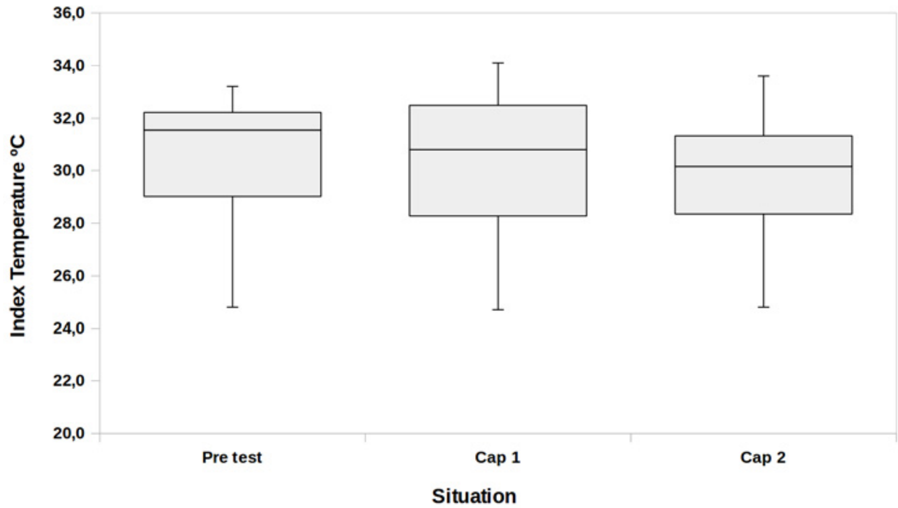

Fig. 6. Measured temperature on index site before the experiment, after the attempt using cap model 1 and 2. (Source: the author)

4. Discussion

Analyses of the applied torque force indicated there were no significant differences between the two attempts, regardless of the cap model. For the cap models analyzed, it was found that the model with larger contact area and smoother grooves (model 2) provided the application of torque forces significantly higher than the model with smaller contact area. This difference is remarkable, since the reduced size and variability of the sample. In this sense it is worth to note that, in a previous study [8], differences in applied forces between cap models have been noticeable with a sample of 60 subjects.

There were no differences between the temperatures measured at the three points. In this case, it could be noted that, in general, the initial average hand temperature before testing was higher. Although not significant, it can be seen that the model 1 caused a bigger reduction of temperature, compared to the model 2. This suggests that the pressure on the tissues was slightly higher, which caused the reduction of blood flow on the site. There was also a great variability in measured temperatures between subjects in each of the three points analyzed.

In general, the temperature variations were not significant. Thermography is likely not suitable for this kind of evaluation. It should be emphasized that the sample analyzed was small for the application of ANOVA, but the proximity of the mean values is already an indicative of their equivalence. The differences between the analyzed cap models might be better understood with the discomfort evaluation, since there have been several reports about nuisances caused by the slots, especially for the cap 1.

This study was experimental and exploratory. Although there are many studies involving thermal images of the skin, most of them deal with temperatures before and after more intense physical activities, like sports or work. The use of such technique as a possible indicator of differences between manual interface design is incipient. Deeper, more insightful and with larger sample studies can be conducted to confirm or refute the applicability of such technique.

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