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Correlation among cap design, gripping technique and age in the opening of squeeze-and-turn packages: A biomechanical study

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ABSTRACT

Child-Resistant Packagings (CRPs) are important because they prevent children accessing potentially harmful products. However, the locking mechanism located on the caps still presents usability problems, especially for elderly users. The aim of this study was to evaluate the effects of packaging design, gripping technique and age in the transmission of torque when opening packages with squeeze-and-turn closures. Three different packages of mouthwashes (squeeze-and-turn type) were analyzed and two gripping techniques were used: tridigital and bidigital. The sample comprised one hundred subjects across five age groups equal in size (3–5 years; 8–12 years; 13–17 years; 30–59 years; over 60 years). For maximum torque measurement, the packages were adapted to receive a torquimeter internally installed and connected to the cap. The results show that packaging design, gripping technique and age are factors that influence the transmission of torque when opening squeeze-and-turn packages. In terms of the packaging design, the cap with the largest diameter allowed the application of higher torques. The opening process using the tridigital gripping presented higher values than the bidigital. In terms of the relative strength of grip across the age groups, children from 3 to 5 years presented the lowest torque values. However, the torque transmission with tridigital grip for children under 5 years old was higher when compared to the bidigital grip for all groups and packagings. The current findings provide biomechanical data on opening squeeze-and-turn packages, contributing to the design of packages that best balance safety and usability.

1. Introduction

Every year, about 35,000 children from 0 to 14 years old die as a consequence of unintentional intoxication (Gordon et al., 2004). In an effort to limit children's access to toxic substances, special packaging opening systems – Child-Resistant Packaging (CRP) – have been used in a number of products. Despite the importance of CRPs in the reduction of accidental intoxication among children, many users (mainly the elderly) experience problems in accessing the package content. Therefore, ergonomic studies on the biomechanics of opening CRPs are needed to clarify the underlying aspects that lead to the success or failure in CRP safety.

The efficacy of CRPs in restricting a child's access to it must be at least 85% without previous instruction or demonstration, and not less than 80% after it. The international standard "ISO 8317:2004 CR packaging – Requirements and testing procedures for reclosable packages" (ISO, 2003) establishes test methods to limit the access of children and ensure accessibility for adults between 50 and 70 years old.

The packaging opening process has been addressed by many studies. Many of these show that older adults experience difficulties and limitations in the packaging interaction (Berns, 1981; Voorbij and Steenbekkers, 2002; Fair et al., 2008; Carse et al., 2011). Although the packaging design should be intuitive, suggesting a specific action of opening, the strategy chosen varies from user to user (Rowson and Yoxall, 2011). Other studies have also evaluated the torque transmission by the hands and fingers (Su et al., 2009), as well as the relationship between the materials and the opening process (Andreasson and Jönsson, 2014).

In the case of CRPs, many studies have shown concern about the usability of this kind of packaging, highlighting the danger that

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children still can access the content of such products (Assargaard and Sjoberg, 1995; Rodgers, 1996; Schmidt et al., 2004). In addition, it is known that the elderly population has great difficulty in opening CRPs (Nayak, 2002; Ward et al., 2010 . Bix and de la Fuente, 2012), and this problem may lead to inappropriate actions, such as transferring the content to an easy-to-open recipient, leaving the CRP uncapped, or simply emptying the content into drawers or bags (Winder, 2009).

While there has been considerable research on specific aspects of the opening process of CRPs, to our knowledge, no studies correlate the packaging design, the gripping technique and the age of the subjects. This is important since these variables are factors that greatly influence the opening process. Therefore, this study aimed to assess the influence of the cap design, the prehension technique and the age in the torque transmission when opening squeeze-and-turn packages. This knowledge may benefit designers and manufacturers by providing biomechanical parameters to be used in the design of packaging that best meet users' abilities, needs and expectations, favoring the product ergonomics.

2. Materials and methods

This study was carried out in the Ergonomics and Interfaces Laboratory at Univ. Estadual Paulista – UNESP, Bauru, Sao Paulo, Brazil.

2.1. Participants

A total of 100 subjects voluntarily participated in this study. The sample was equally divided into five groups of different age intervals: 3–5 years (avg = 4.68; s.d. = 0.47); 8–12 years (avg = 10.30; s.d. = 1.03); 13–17 years (avg = 15.60; s.d. = 1.17); 30–59 years (avg = 45.90; s.d. = 6.81); above 60 years (avg = 74.67; s.d. = 9.08). Each group comprised 20 subjects (10 male; 10 female). The younger subjects (groups 3–5, 8–12, 13–17) were recruited in municipal schools from Bauru, Sao Paulo, Brazil. The subjects in the 30–59 years and over 60 years groups were individually invited to participate in the study.

2.2. Materials

Three different squeeze-and-turn packages of mouthwashes were evaluated in this study (Fig. 1). These packages were selected because they are popular brands, easy to find and they have different designs of cap. The containers are made of Polyethylene Terephthalate (PET) while the caps are made of Polypropylene (PP). The caps are flexible enough on the bases to allow a degree of deformation that is necessary for the opening. To open this type of package it is necessary to squeeze the side tabs of the cap, so that the lugs on the cap are deformed away from the container. While squeezing the cap it is also necessary to turn it, this way the cap's lugs override those on the container, enabling the opening (Fig. 2).

In order to measure maximum torque applied to the caps, a torquimeter (Static Torque Screwdriver - STS - Mecmesin Ltd., UK) was internally installed in the packaging and connected to an extension attached to the cap (Fig. 3).

2.3. Methods

Torque measurements were taken for each subject with the three packages using two gripping techniques: bidigital and tridigital (Fig. 4). Subjects were instructed to hold the packaging at the height of the abdomen and turn the cap with their maximum strength. The sequence of packages and gripping techniques were randomized with online software (www.random.org). A single torque measurement was taken for each packaging and gripping technique; therefore each subject performed a total of six trials, with one minute rest interval between the trials.

Prior to data collection, volunteers read and signed an informed consent form that had been approved by the Ethics Committee of Faculty of Science (Process n. 254.413/2013). In the case of the children, the Consent was obtained from their parents or guardians.

2.4. Data analysis

The average (and standard deviation) torque was obtained for each group of subjects in each of the six situations (two gripping techniques and three packagings). The condition of normality (Shapiro Wilk's W test) and homogeneity (Levene's test) of data were verified. In order to compare the average torque among the groups, ANOVA test was applied to normal and homogeneous data to compare both devices. Non-parametric tests were applied (Friedman, Kruskal-Wallis, Mann-Whittney or Wilcoxon) to the data sets that did not meet these conditions. All results were considered significant at a P value of 0.05 or less.

3. Results

The results for the average maximum torque for the three packages and two gripping techniques among all groups are summarized in Fig. 5. Grip technique was shown to be a key factor influencing torque transmission when opening CRPs. For all the subjects groups, maximum torque was significantly greater with tridigital prehension than bidigital for all the packages.

Overall, the transmitted torques of children (3–5 years) were lower than all other groups when opening the three packagings, taking each prehension technique separately. Furthermore, the maximum torque measurements of the elderly group were lower when compared to adults (30–59 years), with significant difference found only for the packaging with cylindrical cap.

Considering the cap design, the greater maximum torques were found in the packaging with inverted conical cap for all groups and both gripping techniques, with significant differences when compared to the packaging with conical cap. When it comes to gripping technique, the tridigital torque measurements for the packaging with conical cap were the lowest values for all groups.

Possibly the main finding of this study is that the torque transmission with tridigital grip for children under 5 years old (the risk group for accidental poisoning) was higher when compared to the bidigital grip for all groups and packages.

4. Discussion

Research on the ergonomics of packages has been of increasing interest as it influences both product usability and marketing. Although the importance of ensuring the safety of the CRPs in order to prevent children having access to potentially harmful content is recognized, the mechanism of locking-opening the cap has affected product usability among adults and the elderly. Therefore, the investigation into the factors influencing torque transmission in opening CRPs may provide objective parameters that may be of great interest for designers and manufacturers in developing packages that can be both protective and usable. To our knowledge, this is the first study that addresses the biomechanics of opening squeeze-and-turn packages that correlates packaging design, gripping technique and user age.

In general, the most immediate biomechanical strategy for opening a screw-cap packaging is through the use of tridigital grip. When opening CRPs, users usually do not search for informative instructions in the package about the correct opening technique

Fig. 1. Mouthwashes (squeeze-and-turn packages): differences in the design of the bodies (above) and caps (in detail below). Measurements are in millimeters.

(Bonfim and Paschoarelli, 2015). Instead, they make use of tridigital grip to exert a level of force that is enough to open the packaging. The evaluation of maximum torque transmission may provide objective data supporting the design of squeeze-and-turn caps, preventing them from being opened by children as well as keeping the locking mechanism undamaged and, consequently, optimizing packaging safety.

Age is a factor that influences manual force. We found reduced torque measurements for the two extreme age groups: young children and the elderly. Furthermore, the decline in the ability to exert force started at around sixty years. Our results corroborate with the study of Yoxall et al. (2006), which showed that maximum applicable torque in lid opening begins to decrease around the age of sixty for both males and females. Indeed, previous studies (Shim et al., 2004; Kapur et al., 2010) have already shown that the decrease in force due to aging mostly affect distal muscles. This is an important finding that, ultimately, affects the openability of everyday products and therefore must be taken into account by designers and manufacturers in the design of packaging.

The cap diameter is directly related to maximum torque transmission: for both gripping techniques and all the groups, maximum torque was obtained with the cap of largest diameter (packaging with inverted conical cap). This is consistent with previous studies reporting greater torque transmission with a larger diameter in manually-operated devices (Kong et al., 2007; Kong and Lowe, 2005a, b). Crawford et al. (2002) found higher torque exertion measures when the cap diameter increased from 20 mm to 50 mm. However, it is important to highlight that the findings of the present study are restricted for the three evaluated packages and, therefore, are not representative of other packages that use the squeeze-and-turn opening system.

The grooves on the caps were another factor that might have influenced the application of force. Here it is important to note that the step-by-step for opening squeeze-and-turn packages requires the simultaneous application of two directions of force: one that is perpendicular to the tabs (squeeze), and a tangential force (torque) for turning the cap. These two force components must be applied on the cap's tabs for the correct opening. Only the inverted conical cap has grooves on the parts that must be squeezed (tabs), helping opening with bidigital prehension by increasing the friction between the cap and fingers when turning the cap as a following action after squeezing. In contrast to the inverted conical cap, the

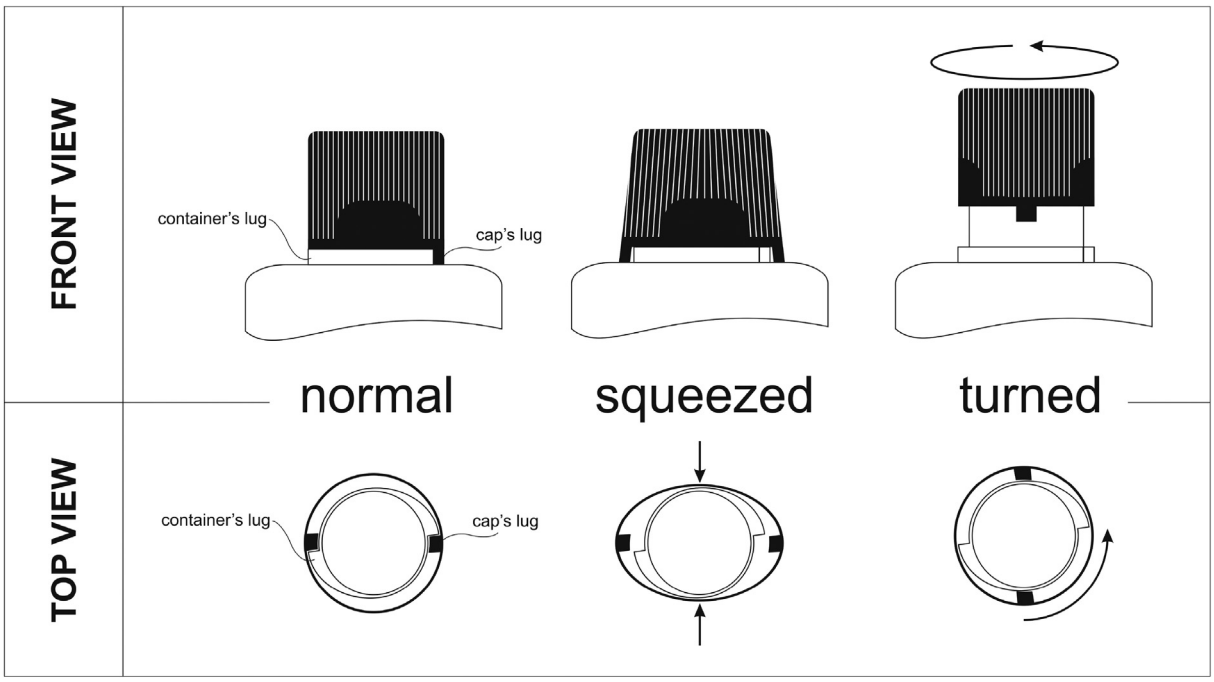

Fig. 2. Opening mechanism of a squeeze-and-turn cap.

Fig. 3. Torquimeter mounted inside the package.

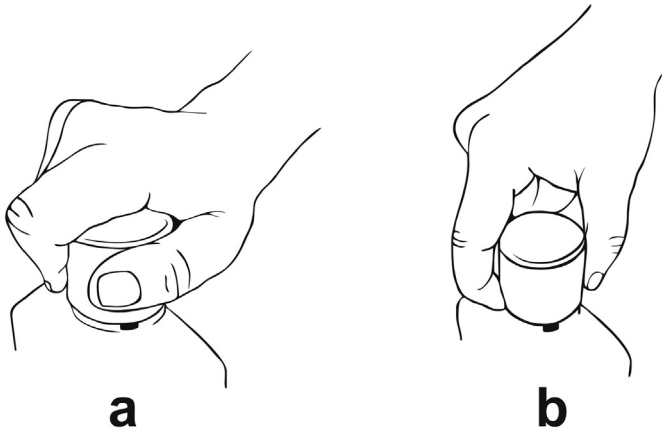

Fig. 4. Gripping techniques: (a) tridigital; (b) bidigital.

conical cap and the cylindrical cap have grooves in all their external area, except on the parts that should be squeezed, which does not provide enough friction for the application of the tangential force, thus making the turning movement difficult. Therefore, the design of squeeze-and-turn caps must provide features that help the user to apply both perpendicular and tangential forces when opening the package. Previous studies have highlighted the role of friction during torque transmission (Yen et al., 2013; Rowson and Yoxall, 2011; Yoxall and Janson, 2008; Lewis et al., 2007).

The youngest children (3–5 years) are considered a risk group vulnerable to accidental poisoning. As they generally make use of tridigital prehension as a strategy to open screw-cap packages, maximum torque data is therefore an important aspect that may greatly contribute to helping industry provide objective parameters for safety in squeeze-and-turn packages. Surprisingly, we found that children aged 3–5 years were able to apply greater torque with tridigital technique than all the other groups with bidigital prehension. This is alarming considering that the cap is made of polypropylene and its lug is a small protrusion that may be potentially damaged as a consequence of repeated improper opening of the product.

Although the current study provides important information on the biomechanics of opening CRPs, it has some limitations that need to be noted. First, maximum gripping force was not measured and, therefore, the relationship between torque measurement and gripping force cannot be established. In order to collect torque data, packages content was drained so that a torquimeter was placed inside them, which led to a slight increase in their weight, but the

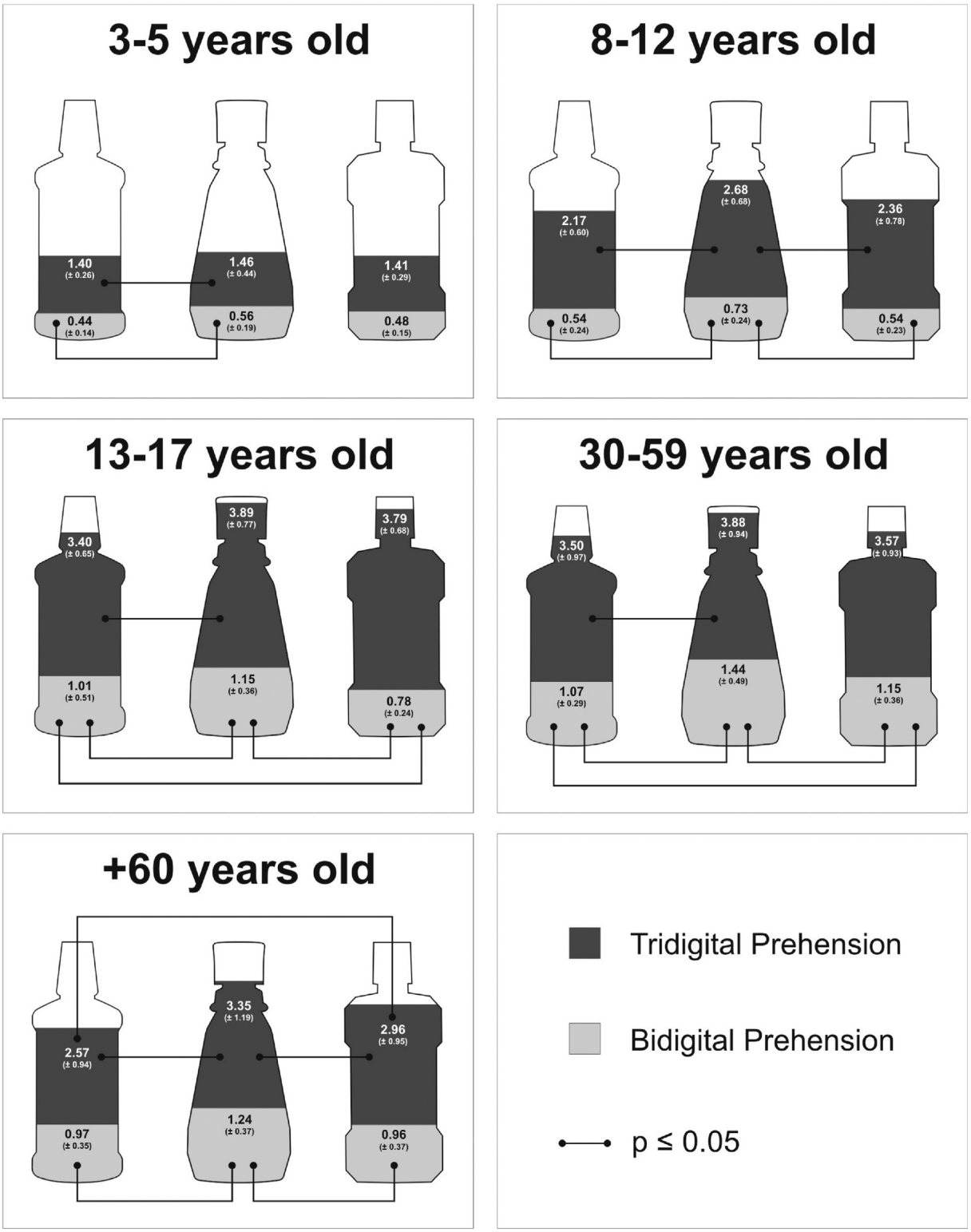

Fig. 5. Summary of average maximum torque of all groups, packagings and prehension techniques. Torque values are presented in N.m.

packaging shape, cap-hand interface and thus handling of the bottle were not affected. Additionally, each subject performed a single trial for measuring maximum torque for each of the six evaluated conditions (three caps, two gripping techniques), as performing three trials per test could be particularly exhaustive for both the children and the elderly. Indeed, Haidar et al. (2004) suggest that one single measurement is not enough for grip strength tests, although they found that, in most of the cases (76%), subjects performed the maximum force in the first trial.

Our study focused exclusively on biomechanics interaction, however the successful design of this type of packaging must consider not only the biomechanical, but also the cognitive aspects

related to opening process. Preventing children from accessing the content of potentially harmful products and, at the same time, ensuring product usability by all other users must be the target of designers and manufacturers, in order to ensure that products can be used with efficiency and satisfaction. Future studies should correlate biomechanical data of CRPs opening with usability evaluation. This might clarify the relationship between objective variables in a functional context in terms of effectiveness, efficiency and user satisfaction.

5. Conclusion

This study found that the packaging design, gripping technique and age are factors that influence torque transmission in opening CRP. Overall, the greater torque measurements were found with the tridigital grip, with the cap with greater diameter and among adults. Perhaps the main finding of this study is that the youngest children were able to exert greater torque with the tridigital grip than all the other age groups using the bidigital grip. This is alarming because if a child holds the cap in an aleatory position and, at the same time, grips it in the right squeezing position, this child may be able to open the packaging and access its content. However, success in opening Squeeze-and-Turn Packages was not assessed in this study. Considering that the tridigital gripping technique is the most immediate strategy for opening screw-cap packages, and is also related to higher torque transmission than the bidigital grip, it is important that the squeeze-and-turn cap be designed in order to resist levels of torque exertions of tridigital prehension, though without losing its locking mechanism.

Conflict of interest

The authors declare no conflict of interest.

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References

Andreasson, E., Jönsson, J., 2014. Advancements in package opening simulations. Proced. Mater. Sci. 3, 1441–1446.
Assargaard, U., Sjoberg, G., 1995. The successful introduction of child resistant closures for liquid paracetamol preparations. Saf. Sci. 21 (2), 87–91.
Berns, T., 1981. The handling of consumer packaging. Appl. Ergon. 12, 153–161.
Bix, L., de la Fuente, J., 2012. Perceptions and attitudes of people with disabilities and older adults about child-resistant drug packaging. J. Patient Compliance 2 (2), 54–59.
Bonfim, G.H.C., Paschoarelli, L.C., 2015. Visualization and comprehension of opening instructions in child resistant packaging. Proc. Manuf. 3, 6153–6160.
Carse, B., Thomson, A., Stansfield, B., 2011. A novel device for evaluating forces during the dynamic jar opening action – do older and younger adults do things differently? Med. Eng. Phys. 33, 521–525.
Crawford, J.O., Wanibe, E., Nayak, L., 2002. The interaction between lid diameter, height and shape on wrist torque exertion in younger and older adults. Ergonomics 45 (13), 922–933.
Fair, J.R., Bix, L., Bush, T.R., 2008. Biomechanical analysis of opening glass jars using kinematics. In: Langdon, P., Clarkson, P.J., Robinson, P. (Eds.), Designing Inclusive Futures. Springer, London, ISBN 978-1-84800-210-4, pp. 45–53.
Gordon, B., Mackay, R., Rehfuess, E., 2004. Poisoning: hidden peril for children. In: Inheriting the World: the Atlas of Children's Health and the Environment. World Health Organization. Myriad Editions Limited, Brighton, ISBN 92-4-159156-0, pp. 38–39.
Haidar, S.G., Kumar, D., Bassi, R.S., Deshmukh, S.C., 2004. Average versus maximum grip strength: which is more consistent? J. Hand Surg. Br. Eur. Vol. 29B (1), 82–84.
ISO, 2003. ISO 8317 – CR Packaging. Requirements and Testing Procedures for Reclosable Packages. International Organization for Standardization, Genebra.
Kapur, S., Zatsiorsky, V.M., Latash, M.L., 2010. Age-related changes in the control of finger force vectors. J. Appl. Physiol. 109 (7), 1827–1841.
Kong, Y., Lowe, B.D., 2005a. Evaluation of handle diameters and orientations in a torque task. Int. J. Ind. Ergon. 35 (12), 1073–1084.
Kong, Y.K., Lowe, B.D., 2005b. Optimal cylindrical handle diameter for grip force tasks. Int. J. Ind. Ergon. 35 (6), 495–507.
Kong, Y.K., Lowe, B.D., Lee, S.J., Krieg, E.F., 2007. Evaluation of handle design characteristics in a maximum screwdriving torque task. Ergonomics 50 (9), 1404–1418.
Lewis, R., Menardi, C., Yoxall, A., Langley, J., 2007. Finger friction: grip and opening packaging. Wear 263, 1124–1132.
Nayak, L.U.S., 2002. Can older adults use child resistant bottle closures? Gerontechnol. J. 2 (2), 198–202.
Rodgers, G.B., 1996. The safety effects of child-resistant packaging for oral prescription drugs: two decades of experience. J. Am. Med. Assoc. 275 (21), 1661–1665.
Rowson, J., Yoxall, A., 2011. Hold, grasp, clutch or grab: consumer grip choices during food container opening. Appl. Ergon. 42, 627–633.
Schmidt, M.H., Nichols, C.G., Schmidt, E.W., 2004. Do child-resistant caps prevent school age children access to prescription medications? Ann. Emerg. Med. 44 (4), S106.
Shim, J.K., Lay, B.S., Zatsiorsky, V.M., Latash, M.L., 2004. Age-related changes in finger coordination in static prehension tasks. J. Appl. Physiol. 94 (3), 213–224.
Su, F.C., Chiu, H.Y., Chang, J.H., Lin, C.F., Hong, R.F., Kuo, L.C., 2009. Jar-opening challenges. Part 1: an apparatus for assessing hand and finger torques and forces in a jar-opening activity. Proc. Inst. Mech. Eng. Part H J. Mech. Eng. Med. 223, 121–129.
Voorbij, A.I.M., Steenbekkers, L.P.A., 2002. The twisting force of aged consumers when opening a jar. Appl. Ergon. 33, 105–109.
Ward, J., Buckle, P., Clarkson, P.J., 2010. Designing packaging to support the safe use of medicines at home. Appl. Ergon. 41, 682–694.
Winder, B., 2009. The design of packaging closures. In: Theobald, N., Winder, B. (Eds.), Packaging Closures and Sealing Systems. Blackwell Publishing Ltd, Oxford, ISBN 978-184127-337-2, pp. 36–67.
Yen, W.-T., Flinn, S.R., Sommerich, C.M., Lavender, S.A., Sanders, E.B.-N., 2013. Preference of lid design characteristics by older adults with limited hand function. J. Hand Ther. 26, 261–271.
Yoxall, A., Janson, R., 2008. Fact or friction: a model for understanding the openability of wide mouth closures. Packag. Technol. Sci. 21, 137–147.
Yoxall, A., Janson, R., Bradbury, S.R., Langley, J., Wearn, J., Hayes, S., 2006. Openability: producing design limits for consumer packaging. Packag. Technol. Sci. 19 (4), 219–225.