Evaluation of drinking ease relative to the opening diameter and beverage type of aluminum beverage bottles

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1   Evaluation of Drinking Ease Relative to the Opening Diameter and

2   Beverage Type of Aluminum Beverage Bottles

3   Running title: Drinking Ease of Aluminum Beverage Bottles

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Abstract

13 This paper investigates the effects of different bottle opening sizes (28, 33, and 38 mm in diameter) and beverage types

14 (e.g. green tea, carbonated beverages) on the drinking satisfaction of consumers, in order to enhance their comfort levels

15 when drinking from aluminum beverage bottles. A survey of 120 Japanese subjects was conducted, and the 33 mm

16 opening size emerged as the most preferred, irrespective of beverage type. The factor analysis results of the

17 questionnaire show that drinking satisfaction is primarily affected by two common factors: the volume of flow from the

18 bottle to the mouth and the adjustability of the flow. The results of the three-dimensional fluid-dynamics analysis

19 indicate that differences in beverage type could influence what consumers regard as an appropriate flow.

20

21 **Key words:** Ergonomics, Drinking ease, Aluminum beverage bottle, Computational fluid dynamics

22

1. Introduction

24   In addition to rudimentary factors like functionality, performance and price, there are other vital areas like usability,

25 novelty in design, and conformity with fashion, which affect customers' decisions while purchasing products.

26 Manufacturers are, therefore, expected to adopt consumers' sensibilities and preferences in their designs, rather than

27 bank on performance alone for acceptance of their products in the marketplace. From the viewpoint of universal design,

28 it is important to design products that can be used comfortably across all age and gender groups. In order to obtain data

29 for determining consumers' preferences, surveys of trained panelists or consumers are usually carried out, using trial

30 products. The Semantic Differential (SD) method (Iwashita, 1983) and the Factor Analysis (FA) method (Richard, 1983;

31 Shiba, 1979) are typical techniques used in such questionnaires. In addition, this study employs the Kansei Engineering

32 method, initially proposed by Japanese researchers as a system of rendering thoughts and sensations into product

33 parameters, and now used internationally by designers as a design methodology (Nagamachi et al., 1974; Nagamachi,

34 1995, 2000). In the product designing stage, numerical simulation serves as an important cost and time saving tool by

35 averting the need to make a lot of trial products; numerical simulation is used in this study to estimate whether a

36 particular design will be loved by consumers or not. Structure optimization techniques based on the Finite Element

37 Analysis (FEA) have been applied to develop 2-piece aluminum beverage cans and bottles in order to get better

38 performance under various loading conditions; for instance, making the lid light-weight can counter subject to the

39 constraints of the buckling strength and maximize the strength of the bottle bottom against the axial load and internal

40 pressure (Yamazaki et al., 2007; Han et al., 2005). Improved shelf life (the length of time that packaged food can be

41 stored), visual appeal, and price are among the anticipated benefits of these beverage containers. In addition, universal

42 designs based on ergonomics have been applied while developing beverage containers and are expected to enhance

43 consumers' convenience (Han et al., 2004; Han et al., 2006; Nishiyama, 2001; Ueno, 2003).

44   Aluminum beverage bottles with screw tops have been launched in the Japanese market in recent years to meet the

45 modern-day drinking habits of consumers. These can be repeatedly resealed, and are designed to recycle many times

46 better than the resealable PET bottles. In addition, these are used by all consumers, irrespective of age and gender. Thus,

47 the universally used aluminum beverage bottles form the focus of this research, which is based on ergonomics and the

48 Kansei engineering evaluation method that considers physiological and psychological effects on human respondents.

49 Consumers in general have several ways of drinking: directly from the bottle opening, with a straw, or from a glass.

50 Because aluminum beverage bottles can be resealed, consumers often take these with them outdoors, and drink directly

51 from the opening. It is, therefore, important for makers of aluminum beverage bottles to consider minutely the

52 satisfaction levels of consumers drinking directly from the bottle opening. Although aluminum beverage bottles with 28

53 mm and 38 mm opening diameters are familiar to Japanese consumers, a majority of them feels that the 28 mm opening

54 is too small and considers the 38 mm opening too large. Researchers have, in the past, conducted studies concerning the

55 "openability" of the closures of food and beverage containers. These studies were based on mechanical evaluation,

56 which considered force, torque and friction (Lewis et al., 2007; Yoxall and Janson; 2007; Carus et al., 2006). The

57 subject of drinking ease (in relation to the attributes of beverage containers) has, however, not been studied so far; this

58 is because a study of drinking ease is dominated by the sensory evaluation of consumers, which makes it difficult to

59 adopt traditional mechanical evaluation techniques. Therefore, we need to develop a method to evaluate human feelings

60 when drinking directly from the bottle opening and then identify the opening size that is most suitable for consumers'

61 drinking satisfaction.

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In addition, physical factors of drinking satisfaction should be extracted so as to evaluate the drinking satisfaction quantitatively, and the flow in the bottles or the flow rate at the bottle outlet may be related to the drinking satisfaction. Consequently, subjective evaluation (i.e. drinking test and the FA method) and numerical analysis (i.e. fluid-dynamics analysis) will support each other, and they will evaluate the effects of the bottle opening size on drinking satisfaction. At first, this paper analyzes data from a survey of 120 young Japanese subjects, based on a drinking test that is conducted using three kinds of experimental bottles with opening diameters of 28 mm, 33 mm and 38 mm. In addition, green tea and a carbonated beverage (coke) were selected as test beverages so as to investigate the influence of the beverage type. Questionnaires based on the Kansei Engineering method were circulated, and the drinking test was performed. The results of the test are statistically analyzed to yield data that will determine, in the course of this paper, the consumers' preference among the three opening sizes. The FA technique is used to identify the factors that influence consumers' drinking feelings and investigate the extent of such influences. Further, a fluid-dynamics analysis model is developed to simulate the flow of bottled liquid during a drinking action. The factors influencing the drinking feeling are evaluated numerically, based on the results of the survey and the experimental observations of consumers' drinking actions.

2. Survey on the Drinking Test

2.1 The Drinking Test Method

The survey had 120 young Japanese volunteers as respondents: 60 males and 60 females. All of them are college or university students, and are between 20–26 years of age. Although this study had intended to cover all age groups, the respondents were exclusively young students because their cooperation was obtained without any difficulty. As shown in Fig.1, all subjects sat while drinking and then filled out questionnaires that aimed to define the extent of drinking satisfaction.

Fig.2 shows samples of three kinds of experimental bottles with opening diameters, 28 mm, 33 mm and 38 mm. The 28 mm and 38 mm opening diameters are familiar to Japanese consumers, but a majority of them feels that the 28 mm opening is too small and the 38 mm opening is too large. Therefore, we predict that the 33 mm opening diameter, which is intermediate in size between 28 mm and 38 mm, will possibly improve drinking satisfaction, and it is selected to be used as the experimental bottle. These bottles have a capacity of 300 ml and are filled with 200 ml of liquid, which allows for an intermediate level of the capacity. All subjects were asked to have one mouthful of drinks from each kind of bottle. The respondents were gathered into six groups numbering twenty each; six different drinking orders were set for the three bottle opening sizes, in order to avoid any possible influence of the drinking order. To investigate the influence of the beverage type, green tea and the carbonated beverage were chosen as test beverages.

The questionnaires, which are based on the Kansei engineering method, are designed to investigate the factors that

influence consumers' feelings while drinking. In general, consumers' feelings may be related to the container (the opening size, shape and material), the beverage type (the temperature and taste), personal factors (the age, gender and way of drinking) and the environment (the place and time). In the engineering context, drinking satisfaction may be affected by the volume of flow into the mouth, and by issues like adjustability and stability while drinking. Eleven evaluation items were selected based on the Kansei model to identify and study the drinking satisfaction. Fig. 3 shows the questionnaire for the 28 mm bottle opening. The evaluation items were the same for all kinds of beverages and bottles. The SD method was used, and five levels were set to calculate responses.

2.2 Statistical Results of the Questionnaire

Figs.4 and 5 show questionnaire results based on the drinking test using bottles filled with green tea and the carbonated beverage, respectively. The mean values and standard deviations are calculated for the eleven evaluation items. It is found that the mean values for the 33mm opening are high in general, no matter what the beverage type. The 38 mm bottle opening shows the highest mean values for Item 1 (Liquid can easily flow out from the bottle), Item 3 (The flow volume through the opening is large) and Item 5 (The flow into the mouth is fast), while the 28 mm opening shows the highest mean value for Item 8 (Liquid hardly spills from corners of the mouth). It is also apparent that the standard deviations of the 33 mm bottle opening are generally lower than that of the other two opening sizes, irrespective of the beverage type.

Since the 33 mm opening shows the highest mean values and the lowest standard deviations for virtually all evaluation items, the 33 mm opening is clearly highly evaluated by all respondents, irrespective of the beverage type. In contrast, the 28 mm and 38 mm bottle openings show relatively high standard deviations, which indicate that subjects have mixed feelings while drinking from these. The 33 mm opening shows a smaller value for Item 3 (The flow volume through the opening is large) but a higher value for Item 2 (The flow volume through the opening is appropriate) when compared with the 38 mm opening. We may, therefore, estimate that there is an appropriate flow of beverages for subjects to feel comfortable when drinking from the bottles.

All subjects were asked to rank the three kinds of bottles in the order of drinking ease so as to determine their preference of opening size. The ranking results for green tea and the carbonated beverage, as submitted by all subjects, are shown in Table 1 (a) and (b), respectively. With 3 points given to the first rank, 2 points to the second and 1 to the third, the total ranking scores of the three kinds of bottles are calculated as shown in the last column of Table 1. It is found that the 33 mm opening scores the highest among the three opening diameters, irrespective of beverage type. The ranking scores are plotted in Fig.6, which facilitates the investigation of the influence of the beverage type and the gender of the drinker on the drinking satisfaction obtained. It is established that the first rank is held by the 33 mm opening in the drinking tests, of both green tea and the carbonated beverage, across both gender groups. Comparing the

4

124 ranking results for the 28 mm and 38 mm openings, it is observed that consumers prefer to drink green tea from a

125 relatively large opening, and carbonated beverages from a relatively small one. However, the differences in scores are

126 small in comparison with the universal preference for the 33 mm opening.

127 　　　To investigate the influence of the subjects' mouth sizes on drinking ease, the width (w) and height (h) of the

128 mouth were measured for all subjects while keeping the mouth naturally closed, as illustrated in Fig.7 (a) (National

129 institute of bioscience and human-technology, 1996). The number of subjects, classified by mouth width into five

130 ranges—(1) 35 mm–40 mm, (2) 41mm–45mm, (3) 46 mm–50 mm, (4) 51 mm–55 mm, and (5) 56 mm–60 mm, and into

131 four ranges of mouth height—(1) 9 mm–15 mm, (2) 16 mm–20 mm, (3) 21 mm–25 mm, and (4) 26 mm–30 mm, are

132 shown in Fig.s 7 (b) and (c). The drinking ease is assigned as shown in Fig.s 8 (a) and (b). Comparing the drinking ease

133 figures attributed to the 28 mm and 38 mm openings in Fig.8 (a), we observe that subjects with large mouth sizes tend

134 to prefer the 38 mm opening to the 28 mm opening. The superceding result, however, is that the 33 mm opening stays at

135 top preference in every category of mouth size. We may, therefore, conclude that the 33 mm opening is best suited for

136 Japanese adult consumers' ease of drinking as its preference is dominant everywhere in our statistical analysis,

137 prevailing in all segments by gender, beverage type and mouth size.

138 **2.3 Results of the Factor Analysis (FA)**

139 　　　The FA is performed in order to gain insight into the data obtained from the responses to the questionnaires. The

140 FA results are shown in Table 2, Table 3 and Fig.9. We can understand the characteristics of identified factors and of the

141 three opening diameters from Fig.s 9 (a) and (b), respectively. Two common factors have been identified. The

142 contribution rate of the 1st factor (54.7%) is greater than that of the 2nd factor (45.3%), which indicates that the 1st

143 factor affects drinking ease more than the 2nd. The communality of the fluctuation rate of the two factors is 95.9%,

144 which implies that the fluctuation in the drinking test results can almost entirely be explained by these two factors.

145 　　　The horizontal axes in Figs.9 (a) and (b) indicate the 1st factor, and the vertical axes represent the 2nd factor. Item

146 1 (Liquid can easily flow out from the bottle), Item 3 (The flow volume through the opening is large) and Item 5 (The

147 flow into the mouth is fast) ascribe large weight to the 1st factor; Item 8 (Liquid hardly spills from corners of the

148 mouth), on the other hand, assigns a small (negative) weight to the 1st factor. Further, Item 2 (The flow volume through

149 the opening is appropriate) and Item 10 (The bottle opening fits with the mouth) ascribe large loads to the 2nd factor.

150 Therefore, the flow amount may be considered to be the 1st factor, and flow adjustability, as the 2nd factor. Good

151 adjustability of flow would imply that the surge of beverage from the bottle opening can be easily and appropriately

152 adjusted, in line with consumer expectations.

153 　　　In Fig.9 (b), the 38 mm opening shows the highest scores for the 1st factor, followed by the 33 mm opening, and

154 the 28 mm opening, independent of the beverage type. In other words, subjects recognize that the flow volume from the

155   38 mm opening is large, followed by the 33 mm and 28 mm openings. The factor score, in the case of the 2nd factor, is

156   highest for the 33 mm bottle opening for any beverage type, which indicates that subjects recognize that the flow

157   adjustability of the 33 mm opening is the best, irrespective of the beverage being consumed. In addition, the difference

158   in the 2nd factor scores between green tea and the carbonated beverages for the 33 mm opening is smaller than that for

159   the 28 mm and 38 mm openings. Therefore, the adjustability between beverage types of the 33 mm opening may be

160   considered more robust than that of the 28 mm and 38 mm openings. Between the 28 mm and 38 mm openings, the 2nd

161   factor score in the case of the carbonated beverage is higher for the former, while in the case of green tea the 2nd factor

162   score is higher for the latter. Thus, the subjects felt that it is easier to adjust when one drinks the carbonated beverage

163   from a bottle with a relatively small opening. This may be explained by the fact that carbonated beverage has a

164   tendency of foaming; thus, the 28 mm opening, which permits a smaller flow amount, makes it easier to adjust than the

165   38 mm opening. Therefore, preferences of the opening diameter's dimensions may change according to the taste and

166   features of beverage types. However, the range of possible preferences is narrow, and centered around 33 mm.

167

168   3. Numerical Simulations

169   **3.1 The Flow-Dynamics Analysis Model**

170   The survey results based on the drinking test show that the beverage flow exerts a great influence on drinking ease,

171   which makes it necessary to develop a three-dimensional flow-dynamics analysis model to estimate the flow-out of

172   beverage from the bottle and to evaluate the drinking ease numerically, instead of relying on experimental observation.

173   The analysis model is developed as shown in Fig.10, and the properties adopted for consideration are tabulated in

174   Table 4. To simulate the drinking action, the bottle model is rotated from its initial upright position to the inclined

175   drinking position at a constant velocity, and then stopped; the entire action is completed in 2.0 seconds. The inclination

176   angle (θ) of the bottle, shown in Fig.10 (b), is defined as the acute angle between the bottle's central axis and the

177   horizontal plane.

178   The velocity boundary condition is applied to the wall and bottom of the bottle (Γ_1, Γ_2), and no relative velocity

179   between the fluid and the bottle is considered. The distributed load boundary condition is applied to the opening of the

180   bottle, defined as the flow outlet (Γ_3), and the pressure on the boundary is equal to zero. The bottle model is filled with

181   200 ml of water, which is assumed to flow out of the bottle without any external resistance. The water and the air in the

182   bottle are assumed to be uncompressible fluids. In addition, the flow in the bottle is assumed as turbulent flow, and the

183   zero-equation type turbulence model with mixing length is applied to the eddy viscosity model. The VOF method is

184   used in order to represent the interface between the water and the air. In addition, the water is assumed to have no

185   surface tension. When the water flows out from the bottle outlet, air that has the same volume as the outflow water

6

flows into the bottle. The computational fluid dynamics analysis code, FIDAP 8.7 (Fluent Incorporated), is used to estimate the flow of fluid during the drinking action. The finite element method is used, and the Galerkin form of the method of weighted residuals and implicit backward Euler are used for spatial and temporal schemes, respectively. Moreover, hexahedral solid elements are used for all models, and the number of nodes and elements are about 55,000 and 60,000, respectively.

The drinking actions of five subjects were recorded using a video recorder in order to measure the final inclination angle (θ_e) of the bottle while subjects performed the drinking action. The average values of the final inclination angles are shown in Table 5. The inclination angles for green tea and the carbonated beverage obtained experimentally have been set on Models named G1, G2, and G3 for green tea and C1, C2, and C3 for the carbonated beverage (Table 6). In addition, $\theta_e = -2.0°$, the same final inclination angle as that of Model G2 (33 mm opening bottle), is set for Model G4 (28 mm opening) and G5 (38 mm opening). All models are started from $\theta = -90°$ and rotated to their final inclination angles.

3.2 Flow-Dynamics Analysis Results

The numerical simulation results of the 33 mm opening bottle (Model G2) are shown in Fig.11. It is observed that the water flows out from this bottle without crashing with the tapered part of the bottle and undulating deeply. Similar behavior of flow is noted in the simulations of the other models.

Fig.12 illustrates the history plots of the flow rates for five models; Table 6 shows the average flow rates of all models, where 'start time' is defined as the beginning of the outflow, and 'end time' is defined as the time at the local minimum point after the 1st peak. In addition, the average flow rate is defined as the average between the start time and the end time. From Fig.12, it can be observed that two peaks appear in the plot for all models, because the second peak is formed by a wave that is reflected by the bottom of the bottle. Moreover, it is observed that the starting time and the duration of the two peaks are almost identical among the five models in spite of the differences in opening size and the final inclination angle. The amplitude of the first peak is different for each of the five models.

If the final inclination angle is given as $\theta_e = -2.0°$, the numerical analysis results of Model G2, G4, and G5 show that the average flow rate of the 33 mm bottle is smaller than that of the 38 mm bottle, but greater than that of the 28 mm bottle. The range of differences is about 50%. However, if the final inclination angles measured experimentally are assigned to the models (G1, G2, and G3), the range of differences in the average flow rate becomes as narrow as about 10%. Moreover, comparing the average flow rate of green tea models (G1, G2, and G3) and that of carbonated beverage models (C1, C2, and C3), it is clear that the average flow rate of the carbonated beverage models is lower for all opening diameters, even though the same material properties of fluid are assumed.

3.3 Discussions

217   Based on the results from the fluid dynamics analysis, it is observed that the flow-out behavior is almost the same

218   in the simulations of all models. Therefore, it is probable that the flow-out behavior of bottled liquid does not affect

219   drinking ease in case of usual drinking actions. On the other hand, the amplitude of the first peak is different for each

220   model. In addition, the flow amount may be considered to be the first factor resulting from the FA of the questionnaire

221   data. Hence, the average flow rate is required, not the maximal value, because multiplying the average flow rate by the

222   duration time gives the flow amount from the bottle opening. Therefore, the average flow rate defined above may be

223   examined to yield a relationship between drinking ease and one of the engineering variables. This agrees with the FA

224   results in that the flow has an effect on drinking ease.

225   The range of differences in the average flow rate of experimental angle conditions is narrower than that of constant

226   angle conditions. If the flow of liquid from the 33 mm bottle is regarded as the appropriate flow, consumers probably

227   adjust the inclination angle of other bottles to achieve the requisite flow for drinking ease. This agrees with the results

228   from the drinking test and the questionnaires that there is an appropriate flow of beverages for subjects feeling

229   comfortable. Moreover, the average flow rate of carbonated beverage models is lower than that of green tea models for

230   all opening diameter. The explanation for this is the propensity for foaming that is inherent in carbonated beverage,

231   which causes its appropriate flow for drinking ease to be lower than that of green tea. Therefore, differences in beverage

232   type could bring about changes in what consumers may regard as appropriate flow.

233   From the statistical analysis of the questionnaires and fluid-dynamics analysis, this paper has established that there

234   is indeed an appropriate level of flow of beverage that allows subjects to feel comfortable when drinking from an

235   aluminum bottle. Especially the average flow rate is an important indicator that allows drinking satisfaction to be

236   evaluated quantitatively. In addition, we have seen that the flow-dynamic analysis model can explain the observations

237   noted in the drinking test and questionnaires, the flow-dynamic analysis model may be utilized to further develop

238   containers that would ensure consumers' ease of drinking. Moreover, it may be concluded that the 33 mm opening is

239   best suited for Japan's young adult consumers across all beverage types, gender groups and mouth size segments.

240

241   4. Conclusions

242   The results of the FA performed with the SD method show the existence of two factors that are primarily

243   responsible for the quality of the drinking feeling; the first factor corresponds to the flow amount and the second factor

244   relates to the flow adjustability. In addition, the results of the fluid-dynamics analysis show that the average flow rate of

245   the bottled liquid may be used to represent the state of drinking ease, and that consumers usually try to realize the ideal

246   flow rate condition by adjusting the inclination angle of the bottle. The results obtained from the fluid-dynamics

247   analysis agree with the FA in that the flow amount and the flow adjustability affect drinking ease. Therefore, it is

248 important that designers of beverage bottles consider, accommodate and utilize these two factors, in order to secure the

249 progress toward greater drinking satisfaction.

250   In order to further enhance the comfort levels of consumers when drinking directly from the bottle opening, the

251 flow-dynamics analysis model developed in this paper may be used to investigate the effects of the bottle shape,

252 opening shape, material and so on. To achieve a developed analysis model for more elaborate evaluation of drinking

253 satisfaction, the number of subjects should be increased. As the next step of this study, drinking actions will be

254 measured by a large number of subjects that cover broad ranges of age, body size, and body shape. In addition, we will

255 also quantify individual differences of drinking actions and the uncertainty of human's behavior. Then an analysis

256 model may be developed to incorporate further details into the analysis, including human mouth sizes, mouth shape,

257 and the role of the hand, in order to investigate the influence of consumers' mouth size, mouth shape, and drinking

258 action on drinking ease. Moreover, the average flow rate will be used as the indicator of drinking satisfaction; that is,

259 drinking satisfaction may be represented quantitatively. Therefore, in future studies, we may specify the rigorous

260 dimension of the opening diameter for drinking ease due to quantitative evaluations of the flow rate.

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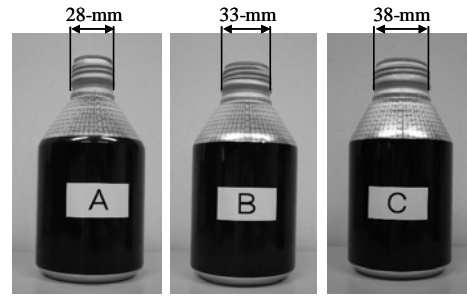308   Fluent Incorporated, *FIDAP User's Manual*.

309

Fig.1 Drinking test

Fig.2 Experimental bottles

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311

(1) Bottle of 28-mm opening

Mark the number with a circle

Evaluation items:	Level:	
1. Liquid can easily flow out from the bottle	5 4 3 2 1	Liquid can hardly flow out from the bottle
2. The flow volume through the opening is appropriate	5 4 3 2 1	The flow volume through the opening is inappropriate
3. The flow volume through the opening is large	5 4 3 2 1	The flow volume through the opening is small
4. Feel comfortable in the throat	5 4 3 2 1	Feel uncomfortable in the throat
5. The flow into the mouth is fast	5 4 3 2 1	The flow into the mouth is slow
6. The flow volume can be easily controlled	5 4 3 2 1	The flow volume can be hardly controlled
7. Liquid flows into the mouth smoothly	5 4 3 2 1	Liquid flows into the mouth not smoothly
8. Liquid hardly spills from corners of the mouth	5 4 3 2 1	Liquid easily spills from corners of the mouth
9. The bottle can be easily inclined	5 4 3 2 1	The bottle can be hardly inclined
10. The bottle opening fits with the mouth	5 4 3 2 1	The bottle opening unfits with the mouth
11. Drinking ease of bottles is better than that of cans	5 4 3 2 1	Drinking ease of bottles is worse than that of cans

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Fig.3 An example of the questionnaire sheets

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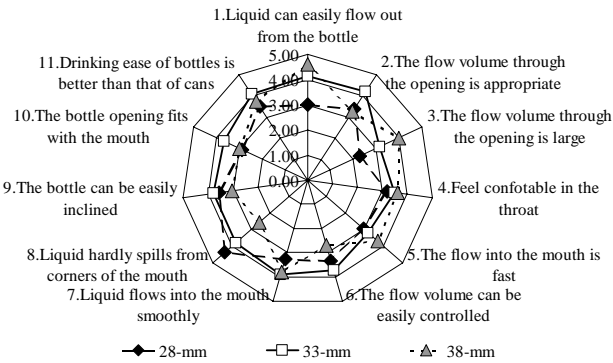
(a) Mean values of 11 items (Green tea)
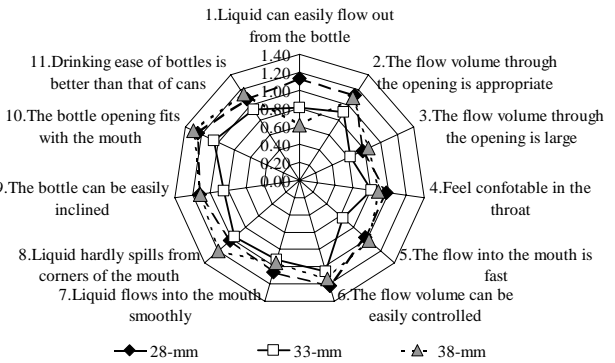
(b) Standard deviations of 11 items (Green tea)

317

Fig.4 Evaluation results of questionnaire (Green tea)

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319

320   (a) Mean values of 11 items (Carbonated beverage)   (b) Standard deviations of 11 items (Carbonated beverage)

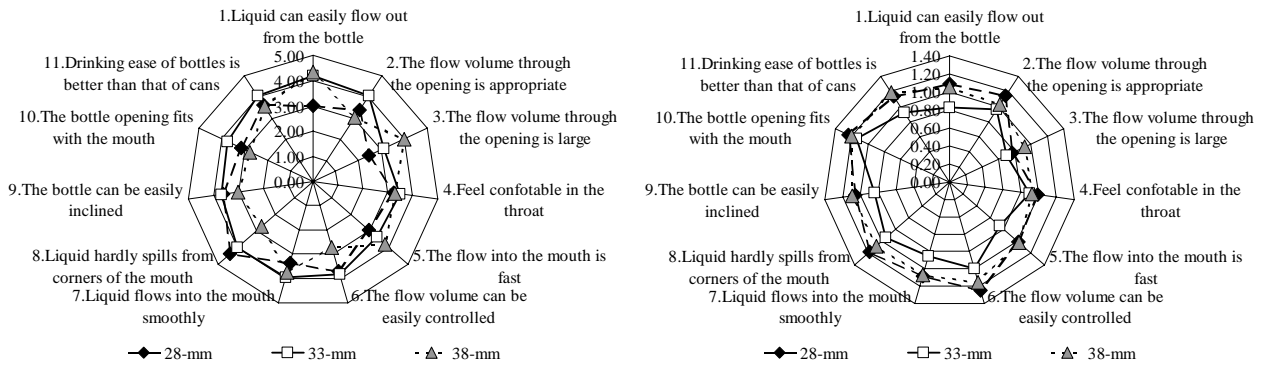321   Fig.5 Evaluation results of questionnaire (Carbonated beverage)
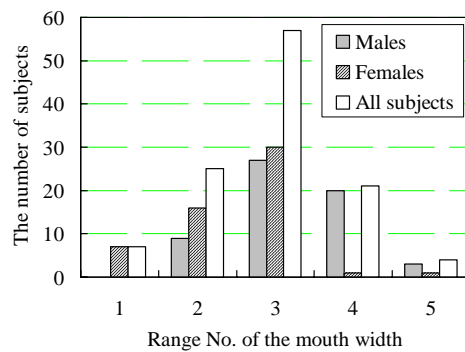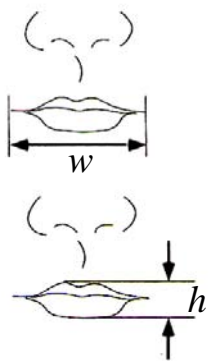
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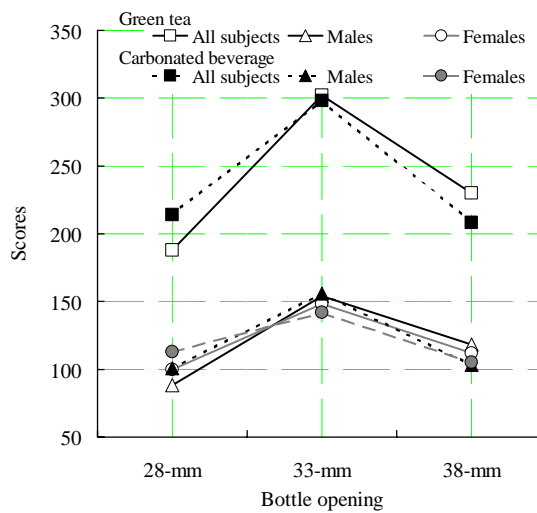
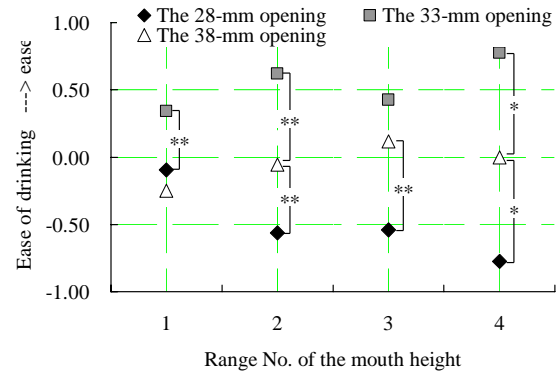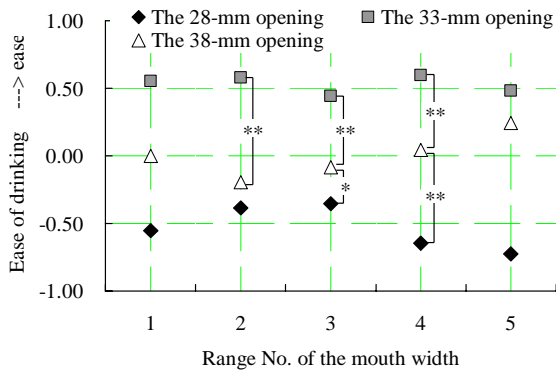324   Fig.6 Ranking results of drinking ease

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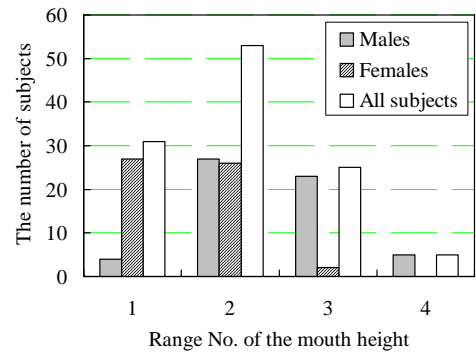
327   (a) Measurement method   (b) Distribution by mouth width   (c) Distribution by mouth height

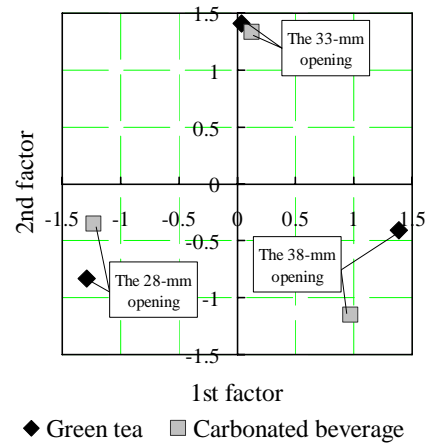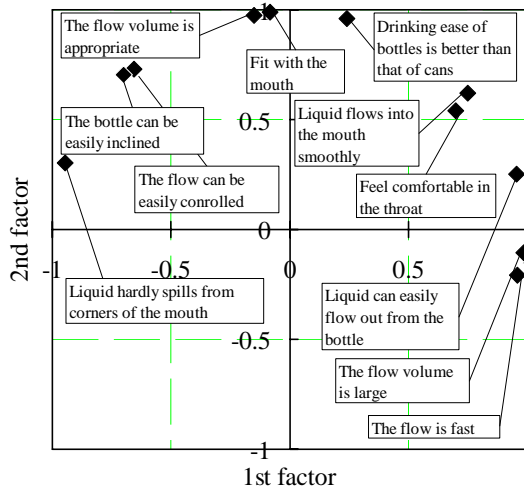328   Fig.7 Distributions by mouth dimensions

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331   (a) Influence of mouth width   (b) Influence of mouth height

332   Fig.8 Influence of mouth dimensions on drinking ease: ** : $p < 0.01$, * : $p < 0.05$

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335   (a) Factor loadings of 11 evaluation items   (b) Factor scores of three kinds of bottles

336   Fig.9 Factor analysis results

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339   (a) Model   (b) Inclination angle

340   Fig.10 Three dimensional fluid-dynamics analysis model

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343   (a) t = 0.00 (θ = –90.0°)   (b) t = 0.80 (θ = –54.8°)   (c) t = 1.60 (θ = –19.6°)   (d) t = 2.40 (θ = –2.00°)
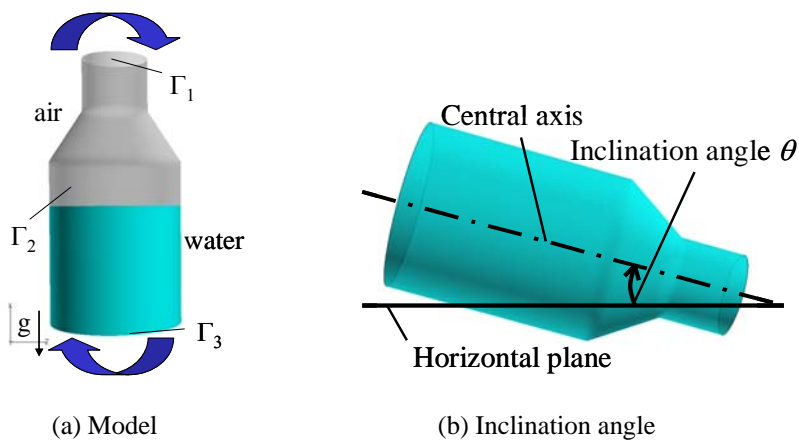
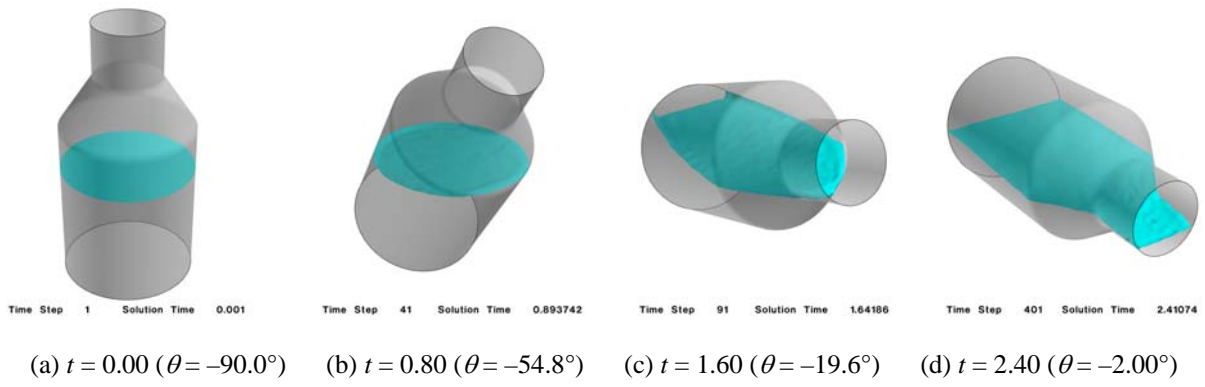344   Fig.11 Fluid-dynamics analysis results

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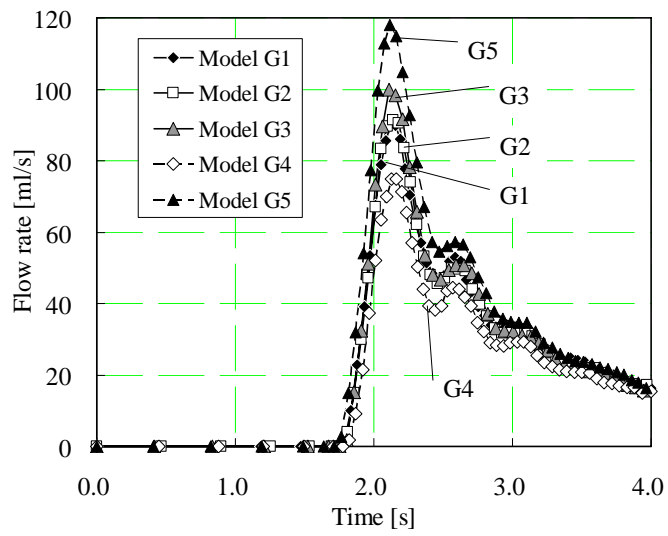347   Fig.12 History plots of the flow rate

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Table 1 Ranking results of drinking ease

(a) Green tea

Sample	Number of subjects			Scores
	1st	2nd	3rd	
The 28 mm opening	16	36	68	188
The 33 mm opening	71	40	9	302
The 38 mm opening	33	44	43	230

(b) Carbonated beverage

Sample	Number of subjects			Scores
	1st	2nd	3rd	
The 28 mm opening	26	42	52	214
The 33 mm opening	70	38	12	298
The 38 mm opening	24	40	56	208

Table 2 Factor loadings obtained in the factor analysis

Items	Factor loadings		Communality
	1st factor	2nd factor	
1.Liquid can easily flow out from the bottle	0.96	0.25	0.98
2.The flow volume through the opening is appropriate	–0.15	0.98	0.97
3.The flow volume through the opening is large	0.99	–0.11	0.99
4.Feel comfortable in the throat	0.70	0.54	0.78
5.The flow into the mouth is fast	0.96	–0.21	0.96
6.The flow volume can be easily controlled	–0.66	0.73	0.96
7.Liquid flows into the mouth smoothly	0.75	0.62	0.95
8.Liquid hardly spills from corners of the mouth	–0.95	0.30	0.99
9.The bottle can be easily inclined	–0.70	0.70	0.99
10.The bottle opening fits with the mouth	–0.08	0.99	0.99
11.Drinking ease of bottles is better than that of cans	0.24	0.96	0.98
Contribution quantity	5.77	4.77	10.5
Contribution rate (%)	54.7	45.3	100
Fluctuation rate (%)	52.5	43.4	95.9

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Table 3 Factor scores obtained in the factor analysis

Sample	1st factor	2nd factor
28 mm (Green tea)	–1.29	–0.83
33 mm (Green tea)	0.04	1.41
38 mm (Green tea)	1.39	–0.41
28 mm (Carbonated beverage)	–1.23	–0.35
33 mm (Carbonated beverage)	0.12	1.33
38 mm (Carbonated beverage)	0.97	–1.15

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Table 4 Properties of the fluid-dynamics analysis

Materials	Density [kg/m^3]	Viscosity [Pa·s]
Water	998	1.00×10^{-3}
Air	1.20	1.82×10^{-5}

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Table 5 Final inclination angles of the fluid-dynamics analysis

Beverage type	Final inclination angle θ_e [deg]		
	28 mm	33 mm	38 mm
Green tea	0.00	–2.00	–4.00
Carbonated beverage	–3.50	–4.00	–6.00

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Table 6 Average rate of flow

Sample	Final inclination angle θ_e [deg]	Start time [s]	End time [s]	Average flow rate [ml/s]
Model G1 (28 mm)	0.00	1.77	2.49	55.1
Model G2 (33 mm)	–2.00	1.79	2.46	57.7
Model G3 (38 mm)	–4.00	1.78	2.48	60.1
Model G4 (28 mm)	–2.00	1.80	2.42	46.7
Model G5 (38 mm)	–2.00	1.74	2.47	70.8
Model C1 (28 mm)	–3.50	1.83	2.42	40.1
Model C2 (33 mm)	–4.00	1.82	2.46	47.2
Model C3 (38 mm)	–6.00	1.82	2.46	49.4

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