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Original scientific paper

Investigation of Factors Influencing Ergonomic Characteristics of Water Bottle Handles

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Abstract: Increasingly competitive market environment pushes products and their packaging to meet functional and aesthetic requirements and expectations of consumers. Ergonomic features are one of the most important features for fulfilling consumer expectations and achieving a satisfying user experience. Drinking water in retail is commonly packaged in PET bottles ranging from 0.2 up to 6 litres. The weight of the 6-litre bottle is roughly 6 kilos which can produce strain on the hand while carried from the place of purchase to the place of usage. The goal of this research was to investigate the influence of water bottle handles and to determine how much does handle length, width, and curvature of the grip's edges affect the comfort of product use. This research presents objective experimental measurements and subjective judgment regarding ergonomic characteristics of the 5-6 litre water bottle handles, based on the variations in their shape and dimensions.

Keywords: ergonomics, handles, packaging, water bottle

1 INTRODUCTION

Ergonomics is a scientific discipline that deals with understanding the interaction between people and other systems in order to optimize human well-being and overall system performance. Factors like human posture and body movement, environmental factors, must be considered for achieving good ergonomics, safety, comfort and efficient performance in daily life [1-5]. Hand-Held Industrial Products (HHIP) are products that undergo manual manipulation. Poor design of HHIPs and their long-term use can cause early tiredness of the hand and various musculoskeletal injuries. Often user's abilities are not considered during the product development [6]. Assessment of psychological, morphological, physiological and biomechanical behaviour of the user while using the product, and including anthropometric and physical measurements of the users can help improve the quality of the product [7]. Similarly to HHIPs the ergonomics design is of crucial importance for the product packaging, especially if the product is of considerable weight such as water packaging which can reach 5 to 6 kilos and is daily handled at the retail and the place of use. The research focused on the ergonomic development of hand-held industrial products is primarily conducted in the hand tools investigation. Comfort and discomfort are of crucial importance in hand tool ergonomics, and they are frequently used as an evaluator of ergonomic design of hand tools and as a predictor of musculoskeletal injuries [8]. For describing the subjective judgement of hand tools, comfort is associated with positive feelings of reliability, safety, ease, and satisfaction, whereas discomfort is associated with negative feelings of pain, pressure, hardness, and irritation [9]. Researchers have investigated many different hand tools in terms of comfort and discomfort, such as garden tools [10], handsaws [11, 12], knives [13], handles for the chisel and the off-set pliers [14-16], sanders [17], screwdrivers [18, 19], wire-tying hooks [20, 21], carpet weaving tools [22], hand tool handles in hand-woven shoemaking operation [23], handles for grab rails or ladders [24], meat hook handle [25], mason's trowels [26], axes [27], spray guns [28], etc. The water packaging also undergoes manual manipulation and the same methodologies can be applied here. Since there are various forms and sizes of packaging, the end-user is required to use different gripping techniques, movement and to apply a large amount of force. Water packaging (bottle) offered in the market can reach 6 litres in its volume, thus the handle is needed for manipulation. Due to considerable weight the use of such packaging with poorly designed handle can produce intense physical pressure and pinched nerve, causing finger numbness. An ergonomically designed handle makes the wrist flexion/extension or ulnar/radial deviation minimal and allows the user to maintain a neutral wrist posture and has a huge influence on the judgement of comfort and discomfort of the handle [23]. To determine the influencing factor of comfort and discomfort of hand tools and handles in general, many researchers investigated handle features such as handle length [11], size [29, 30], shape [31-34], material [10, 12], weight [28], and friction [35]. The shape of the handle is characterized by five characteristics. These characteristics are: handle length, handle width, angle of the handle between the grip and the base, the number of dents and the curvature of the grip's edges. In the previous research [36], focused on handles of the 5 to 6 litre water bottles present in the market, the goal was to determine the influence of the angle of the handle between the grip and the base (contact surface of the bottle and handle) and the number of dents in the grip part of the handle on the feeling of comfort (Fig. 1).

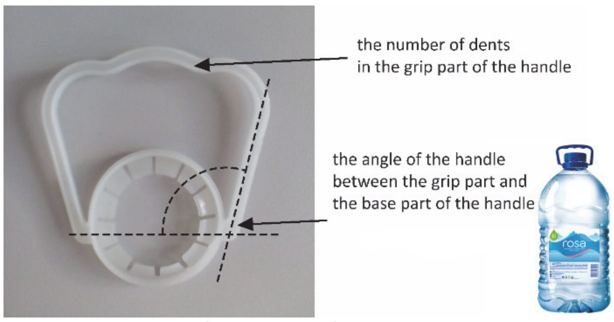

Figure 1 Characteristics of a water bottle handle

It was found that the optimal number of dents for fingers was 4. The angle of the handle between the grip part and the base part of the handle was not an important factor influencing comfort and manual pulling forces.

Taking into consideration results of the previous research [36], this research was designed to investigate other influencing factors on the water bottle handle comfort. Hypothesis of the research is: The shape of the handle significantly influences its ergonomic performance. Larger edge bevel radius of the grip edges will increase the comfort of the handle. A larger width of the handle will lead to a subjective feeling of safety and stability during use. The preference towards handles shape is influenced by the size of the user's hand.

2 MATERIALS AND METHODS

This research aimed to determine the influence of the handle length, width, and edge bevel radius on its ergonomics and consequently use experience. Other researchers also investigated the influence of handle size and shape on measured grip strength, optimal handle grip span etc. [37-39] using similar methodologies. This research was conducted through objective measurements of puling force and subjective judgment of the handle characteristics by a participant survey.

2.1 Experimental Handle Variations

The handle variations used in the experiment were produced using the FDM 3D printing process, MakerBot 5th Generation (Infill 100%, Printing temperature 215°, Printing speed 90 mm/s, Layer height 0,1 mm, PLA material) based on the 3D models constructed using Autodesk Inventor Professional. All surfaces of the 3D printed parts, which are in contact with participant's hand, have been buffed down using sand paper of three different grits, successively. This produced a solid smooth surface by removing imperfections caused by layered material deposition typical for FDM process, making the surface comparable to the surface of the parts produced by injection moulding which is the usual handle production method. An example of a handle and its varied dimensions is presented in Fig. 2.

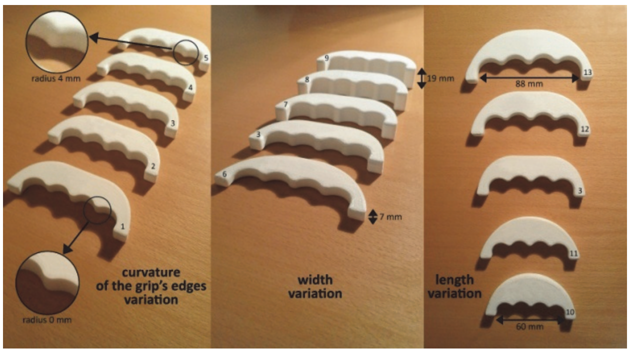

Figure 2 Variations of 3D printed handles width, length and edge bevel radius

As this research examines the three handle characteristics, three groups of handles were modelled with dimensional variations in each characteristic, leaving the other two characteristics constant. In each group, there are 5 variations for each characteristic, but since one handle is repeated in each group, taking the medium "value" of all characteristics, the total number of handles was 13. The dimensions of the tested handles are presented in Tab. 1.

Table 1 Dimensions of modelled handles

Handle number	Bevel edge radius / mm	Handle width / mm	Handle length / mm
1	**0**	10	74
2	**1**	10	74
3	**2**	**10**	**74**
4	**3**	10	74
5	**4**	10	74
6	2	**7**	74
7	2	**13**	74
8	2	**16**	74
9	2	**19**	74
10	2	10	**60**
11	2	10	**67**
12	2	10	**81**
13	2	10	**88**

2.2 Experimental Apparatus

The experimental apparatus was constructed to measure the manual pulling force by which the participants can pull the handles comfortably, as shown in Fig. 3.

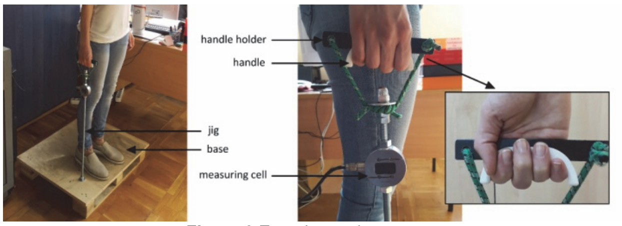

Figure 3 Experimental apparatus

Apparatus consists of force measuring cell (up to 500 N) connected to the jig that enables participants to pull the handle as hard as they feel comfortable, while force is recorded by the Trapezium software. Height of the participant was taken into consideration, so the position of the handle was adjustable by a fully threaded rod, ensuring a comfortable position. The jig was anchored to the base on which participants stand, thus preventing the lifting of the apparatus. The similar experimental apparatus was used in similar research by other researchers, with few modifications to enable connection of the 3D printed handles used in this experiment.

2.3 Participant Selection and Procedure

To collect anthropometric data of hands, which will later help in the analysis and discussion of the obtained results, participants' dominant hands were scanned and archived before experiment using HP scanner at 1200 spi Similar measurements were done in other researches [32, 40, 41]. Based on these measurements, two groups were created, a group of participants with small hands and a group of participants with large hands (Tab. 2).

Table 2 The criteria for the categorization of participants' hands on small and large hands

		Small hand	Large hand
1	Hand length	15.5 (±1) cm	17.5 (±1) cm
2	Grip (finger) width	5 (±1) cm	7 (±1) cm
3	Hand width	7 (±1) cm	9 (±1) cm

The study was conducted with 50 participants. Experimental setup was constructed in order to replicate pressure on the palm while carrying water bottle with handle. In the laboratory conditions it would be hard to reproduce exact real life conditions, where carrying the load while walking produces dynamic forces and the pulling force in the experimental setup is one directional and subjects are stationary. Participants entered the measurement room one at a time, positioning themselves comfortably on the base of the apparatus depending on whether they were left-handed or right-handed. The height of the apparatus was adjusted accordingly. After the task was explained, the participants were instructed to pull the first handle with force suitable to ensure comfort over a longer pulling time and not to use any other strategies in applying pulling force. Participants were informed to start the handle pulling by a specific sound. When the participant heard the sound, their task was to manually pull the handle for 30 seconds. The Trapezium software started counting down 30 seconds after the minimal pulling force of 10 N was reached, while the pulling force was monitored and recorded. If the participants experienced pain or tingling sensation in their fingers, they should have reduced the force and pulled the handle by the force that made them comfortable. After 30 seconds the specific sound was heard again which indicated that the test is over and the handle can be released. After each handle, the participants left the measurement room, receiving a questionnaire regarding the comfort of the handle they tested previously. This process was repeated for each handle. Handle variations order was random for each participant. These pauses with active use of the hand while filling the questionnaire were deliberately designed as an integral and very important part of the experiment, to avoid participants' fatigue, as they were given enough time to rest their arm's muscles and nerves of the palm, thus eliminating the effect on the subsequent measurement. Out of 50 participants, 4 of them were eliminated as they did not understand the task correctly or made some mistake in the procedure. Consequently, these results were not taken into consideration.

3 RESULTS

Valid data was collected from 46 participants, 31 female and 15 male. All participants were in their twenties. The average height of the participants was 172 cm (min 157 cm, max 190 cm), and the average weight was 63 kg (min 45 kg, max 88 kg). None of the participants had an injury or any kind of skin problem on his/her dominant hand or palm, as that could affect the results. Only one of 46 participants was left-handed. Alongside demographic questions, questions about handle characteristics were asked, some of which are listed below.

• Do you currently suffer from any palm skin problems? If yes, describe the problem.

• Considering the size of your hand, the size of the handle is: *Too small, *Appropriate size, *Too big.

• Rate the comfort of the handle from 1 to 10 (1 - very uncomfortable, 10 - very comfortable), etc.

After data collection, results were structured into data matrices appropriate for further analysis. Graphical representation of the handle size judgment of all 46 participants can be seen in Fig. 3. Based on the participants' subjective judgment collected by the survey it is noticeable that handles numbered from 1 to 9 were mostly evaluated as handles with the appropriate size, while handles numbered from 10 to 13 were mostly evaluated as too small or too big. Graphical representation of subjective judgement regarding handle comfort from all 46 participants is presented in Fig. 4. It can be seen that handles numbered 1, 7 and 10 were mostly evaluated as uncomfortable handles, while handles numbered 3, 4 5 and 12 were mostly evaluated as comfortable handle.

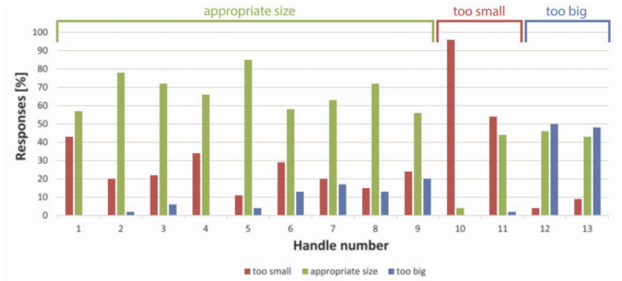

Figure 4 Displaying grades regarding handle size based on the subjective judgment of all 46 participants

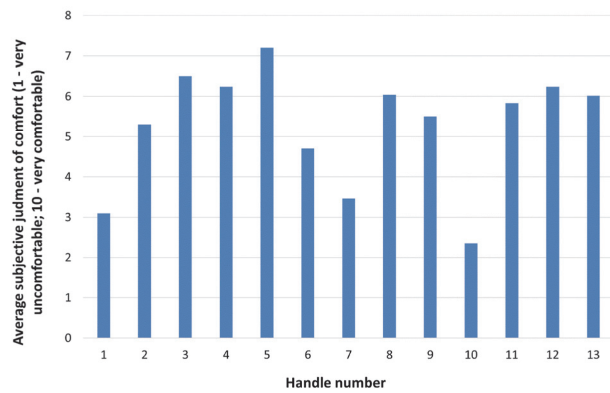

Figure 5 Displaying grades regarding handle comfort based on the subjective judgment of all 46 participants

Values of all 46 participants manual pulling forces, averaged for each point in time (sampled every 0.01s), for handles no. 1-13 are shown in Fig. 6.

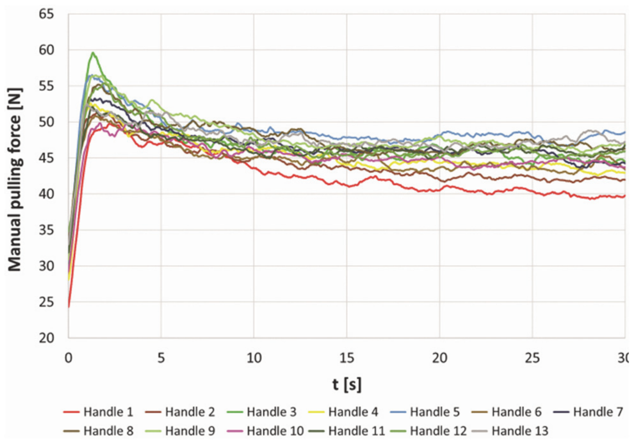

Figure 6 Diagram of mean pulling forces of all 46 participants

A typical curve describes a change of the pulling force intensity during the 30 s period. The maximum force value is applied in the first 2-3 seconds, because the participants pulled the handle up to the moment of discomfort, after which the pulling force decreased until the discomfort stops. After this local extreme, the pulling force is mostly stabilized, with small disturbances caused by participant's adjustments of the body or grip position, caused by fatigue or mild discomfort. It should be noted that some participants did not require adjustments, while others did this several times during the test period. Discomfort caused by the handle shape did influence the frequency of position adjustments.

As can be seen from the graph in Fig. 6, the highest pulling forces were achieved using handle no. 3 (Mean: 46.86 N; St. dev: 21.65 N), no. 9 (Mean: 48.26 N; St. dev: 6.90 N) and no. 5 (Mean: 46.17 N; St. dev: 17.92 N), while the lowest pulling forces were achieved using handle no. 1 (Mean: 41.75 N; St. dev: 15.93 N). Statistical analysis of the results was conducted using SPSS software. A repeated measures' test (one-way repeated measures ANOVA) was used to determine the effect of the handle shape on the manual pulling forces. There was a significant main effect of handle shape on the manual pulling forces ($F(12, 540) = 2.161$, $p < 0.05$). Tab. 3 presents the results of the post hoc test, showing only pairs of handles with a statistically significant difference in mean values of pulling forces.

Table 3 Post hoc results, pairs of handles between which mean values of pulling forces had a statistically significant difference

(*I*) Handle 1-13	(*J*) Handle 1-13	Mean diff. (*I* − *J*)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	4	−3.484	1.476	0.023	−6.456	−0.511
	5	−4.423	1.951	0.028	−8.353	−0.494
	6	−3.031	1.497	0.049	−6.047	−0.015
	7	−5.029	1.931	0.012	−8.919	−1.139
	8	−5.748	2.089	0.009	−9.954	−1.541
	9	−6.514	2.028	0.002	−10.599	−2.429
	11	−4.512	2.219	0.048	−8.982	−0.043
	12	−5.064	1.903	0.011	−8.897	−1.231
	13	−6.067	2.128	0.007	−10.352	−1.781
2	7	−2.985	1.243	0.020	−5.488	−0.482
	8	−3.703	1.452	0.014	−6.628	−0.779
	9	−4.469	1.513	0.005	−7.517	−1.422
	12	−3.020	1.434	0.041	−5.908	−0.132
	13	−4.022	1.436	0.007	−6.914	−1.131
4	9	−3.030	1.408	0.037	−5.865	−0.195
6	8	−2.716	1.318	0.045	−5.371	−0.062
	9	−3.482	1.433	0.019	−6.370	−0.595
9	10	3.148	1.178	0.010	0.775	5.520
10	13	−2.700	1.308	0.045	−5.336	−0.065

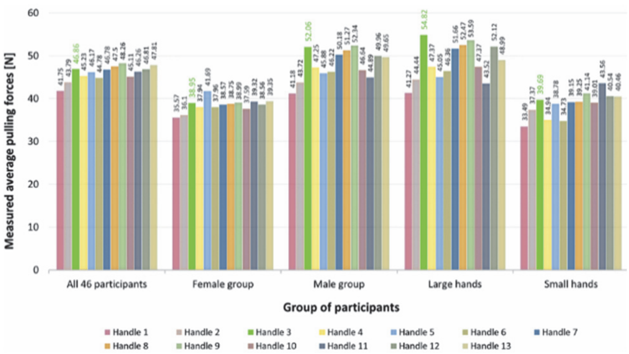

Figure 7 Measured mean manual pulling forces achieved within every group of participants

Measured mean pulling forces within every tested group (group of all 46 participants, female group, male group, large hands group, small hands group) of participants are given in Fig. 7. Tab. 4. shows descriptive statistics of the manual puling force for all 13 handles.

Table 4 Descriptive statistics of the manual puling force for all 13 handles

Handle no.	Partici-pants	Min. pulling force / N	Max. pulling force / N	Mean pulling force / N	St. deviation / N
1	46	11.593	76.254	41.7473	15.9280
2	46	11.340	78.927	43.7915	16.7926
3	46	11.201	137.956	46.8588	21.6498
4	46	13.670	80.021	45.2310	16.6129
5	46	14.301	89.134	46.1705	17.9165
6	46	7.169	96.378	44.7785	17.3028
7	46	9.829	93.383	46.7764	17.3233
8	46	7.125	95.254	47.4950	17.4053
9	46	12.855	103.639	48.2610	16.9094
10	46	15.072	108.625	45.1134	18.5205
11	46	9.213	107.842	46.2597	18.3152
12	46	11.559	94.272	46.8114	17.3496
13	46	9.268	90.734	47.8138	17.8371

4 DISCUSSION

The edge bevel radius - based on the results from both the survey and experimental research, handle no. 1 (mean pulling force of 41.75 N) proved to have the worst ergonomic features. The assessments given in the survey and measured pulling forces for handle no. 2 (mean pulling force 43.79 N) and especially for handle no. 3 (mean pulling force 46.86 N) were higher compared to the handle no. 1. Handle no. 1 does not have the bevelled edge while handles no. 2 and no. 3 have (radius of 1 mm and 2 mm respectively). All participants repeated these results (men, women, small hands, large hands), confirming the necessity of the bevelled edge to assure the comfort of use and the fact that a small radius or sharp edge results in discomfort. Comparing results for handles no. 3 (edge radius 2 mm) and no. 4 (edge radius 3 mm) showed positive subjective, describing them as comfortable handles. However, mean pulling forces are lower for handle no. 4. This difference is pronounced especially in the group of participants with small hands (mean pulling force of 34.94 N). Handle no. 5 (edge radius 4 mm) with almost completely rounded shape of the grip part, received high comfort grades. Female participants produced higher pulling forces (41.69 N), while male participants produced pulling forces of 45.88 N, which was even lower than forces handle no. 4 (47.25 N). Results indicate that the edge bevel radius affects the comfort of the handle, confirmed by statistically significant difference ($p = 0.023$) in the mean pulling forces between the handle no. 1 (without curvature) and handle no. 5 (4 mm curvature). However, it turned out that the radius should not be increased to a maximum, but to a certain value that would suit both genders. This research indicated the optimal radius of 2 mm and that further increase of this feature advances the feeling of comfort only for the female population.

The length feature - the handles characterized as smaller length handles (no. 10 - 60 mm and no. 11 - 67 mm) resulted in high values of mean pulling forces by female participants and participants classified as having small hands. The mean pulling force of the handle no. 11 (46.26 N) was higher than the mean pulling force of the handle no. 10 (45.11 N). Within the group of participants with small hands, handle no. 11 resulted in the highest pulling forces compared to all other handles. On the other hand, a group of participants with large hands using handle no. 11 gave the lowest pulling forces compared to all other handles. Since this handle does not equally suit participants based on their hand size, it could not be defined as a handle of universally ergonomic shape, which should be the goal of handle design. Even though the shortest handle, no. 10 gave similar results in pulling forces tested by both groups of participants with small and large hands. As participants did not get strict instruction describing the grip, but only to grip the handle comfortably, the participants with bigger hand grabbed the handle with three fingers instead of four, as it was intended to be held, since the handle has four finger dents. The amount of material used for the handle no.10 and the high values of the pulling force could be a sufficient reason for selecting this as an optimal handle length. However, since this research is also concerned with an optimal ergonomic shape, the question remains if the three-finger grip qualifies as suitable. Increase in length of the handle no. 3 (74 mm), handle no. 12 (81 mm) and handle no. 13 (88 mm) fulfilled all the requirements for each group of participants while holding them as intended. These handles also resulted in similar values of mean pulling forces, handle no. 3 - 46.86 N, handle no. 12 - 46.81 N and handle no. 13 - 47.81 N. Keeping in mind the trend of reducing the amount of plastic to preserve the environment it should be noted that handle no.3 requires less material than handles no. 12 and no. 13. Based on these findings, handle no. 3 has an optimal handle length of 74 mm.

The width feature - using handle no. 6 (width of 7 mm, mean pulling force 44.8 N) resulted in lower mean manual pulling forces than other handles. These results coincide with subjective assessments of participants in the survey describing this handle as narrow and unstable. It can be noted that with the increase of width, pulling forces are becoming higher, the handle no. 3, 10 mm wide (mean pulling force 46.86 N) and the handle no. 7, 13 mm wide (mean pulling force 46.78 N). Handle no. 8, 16 mm wide (mean pulling force 47.46 N), enables high pulling forces due to the largest surface of the grip part. Handle no. 13, which is 9 mm narrower and 15 mm longer than handle no. 8 can match it in terms of manual pulling forces. By increasing the length, higher force values are achieved more efficiently than by increasing the width, so keeping in mind the consumption of the material, handle no. 13 would be a more optimal shape than handle no. 8. The analysis showed significant statistical differences when comparing handle no. 9 (19 mm in width, mean pulling force 48.26 N) to handle no. 10 (p = 0.01) and handle no. 1 (p = 0.002). Handle no. 9 resulted in the highest or the second-highest mean value of pulling forces in all groups of participants, which suggests that increasing the width significantly contributes to the increase in pulling force. Thus, the larger width of the handle will lead to a subjective feeling of safety and stability in its use. The edge bevel radius of the handle no. 9 is not optimal and the higher radius of the edge could further increase pulling force results. Although the handle no. 9 gave the highest mean value of the pulling force, its production demands the most plastic material.

Taking all the factors in consideration, handle no. 3 fulfils its function most effectively, as it is ranked in the fourth place based on the value of mean pulling forces, surpassed by handles that demand far more material for production. Handle no. 3 also meets the desired subjective feel of comfort and stability in performances favouring it as an optimal shape and dimensions for the 5-6 litre water bottle handle.

5 CONCLUSION

Handles are used in everyday activities of human life. The subject of the research was an investigation of the ergonomic shape of the handles for water packaging. The good ergonomic characteristics of the handle can be achieved by paying attention to the selection of size, shape, weight, texture of the surface, materials and the required grip (affecting the position of the wrist and arm). In this research, the investigation of the ergonomic shape of the handles was conducted through experimental testing of thirteen 3D modelled handles, which had four dents provided for the fingers in the grip part. They differed in length, width, and radius of curvature of grip's edges to find the optimal relation of these three features. Although the pulling force in the experimental setup is one directional and subjects are stationary, while carrying the load when walking produces dynamic forces it can be concluded that the shape of the handle influences its ergonomic performance of the water bottle handle. Results indicate a difference in the pulling force depending on the shape of the handle, and based on the results, the handle of optimal characteristics was proposed. Handle no. 3 (length 74 mm, width 10 mm, edge bevel radius 2 mm) was selected as the handle of the optimal shape. It is very well rated by a group of participants with small hands and also in the group of participants with large hands, although each group used a different grip. Overall, it is ranked in the fourth position, but it requires far less material for the production compared to better-ranked handles no. 9, 13 and 8 (respectively sorted by the value of the mean pulling force, first being the highest). The differences in the mean values of the pulling force of these handles compared to handle no. 3 are not significant enough to justify the greater consumption of materials. Handle no. 9 as the best-rated handle, especially for the male participants, has the same length and edge radius as the handle no. 3 and only differs in width. This means that handle no. 9 would be the handle with the best ergonomic shape if material consumption was not of concern. The research found that the female participants find edge curvature radius as the significant feature. The mean values of the pulling forces of female participants are significantly lower than those of male participants. Having this in mind, it could be recommended that water bottles volume should be reduced to 4 litres in order to optimise it for female consumers. Results of this research could also be useful for the design of handles intended for other uses, besides water packaging, dealing with loads ranging from 4 to 6 kilograms.

Acknowledgements

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