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Experimental studies of the quality of embossed characters of the Braille alphabet

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Abstract. The paper presents studies pertaining to the quality of embossed characters of the Braille alphabet used, among other applications, for tagging drug labels. The following parameters of embossed inscriptions were measured: height, diameter of the dots and surface roughness (18 samples with various combinations of their values). 48 blind individuals assessed the quality of the printed text. Statistical analysis proved that a text with dots having height of 0.9 millimeter, diameter of 1.6 millimeters and roughness Ra of about 1 micrometer to be the best. The samples had been made using two different methods of rapid prototyping: PolyJet and SLS. 3D printing is increasingly popular and the studies proved the usefulness of these methods for labeling with embossed inscriptions, due to the repeatability, durability and quality they ensure. The assessing group of blind individuals was comprised of 24 persons 14–17 years old and other 24 persons aged over 60 who were not proficient in reading Braille alphabet, This allows to conclude that a text featuring the above values of the parameters will be easy to read for the majority of blind persons.

Key words: tactile reading, Braille alphabet, Braille characters, visual impairment, measurement of parameters of Braille dots.

1. Introduction

About 285 million persons in the world live with a dysfunction of sight, of which almost 40 millions are blind [1]. Limitation or lack of the sense of sight is partially substituted by other senses, e.g. hearing and touch. One of the methods of passing on information to a blind person is using embossed text written with Braille alphabet, which is read using tactile sensing.

Nowadays, the public space is more and more often adapted to the needs of the blind by the way of posting Braille information. The Braille alphabet is also used for tagging drug labels. Despite embossed printing being commonly used, there is a general lack of unequivocal recommendation defining how the convex dots constituting the Braille alphabet should look like, so that they would be not only easily read by the blind. The only exception is the standard issued by the European Committee for Standardization [2] (tagging of drug labels is required by law, e.g. in EC [3], [4]), which defines the minimal height of the dots to be 0.2 millimeter. However, various associations of the blind (e.g. Polish Association of the Blind) recommend much higher values, of about 0.5 mm [5]. The other common problem is that, in practice, many makers of embossed prints are not well acquainted with the specificity of tactile reading, and do not set the printing devices correctly. There is also the issue of quality of printing devices available on the market, since poor quality embossed copies may not be read willingly, because the blind are afraid that a surface which is too rough, will cause a decrease of their tactile sensitivity. All of the above convinced the authors that it would be desirable to carry out a study, in which embossed writing parameters (and their values) are analyzed using subjective assessments of the prints by groups of the blind. The aim of the study was to determine values of the parameters of the embossed writing, for which it is easy for the reader to recognize the text.

The studies confirmed the significance of the analyzed factors.

2. The Braille alphabet

Braille is an embossed text writing, in which each letter of the Latin alphabet has its counterpart in a form of an embossed character. Writing of any single letter or other character is based on a system of 6 embossed dots, as illustrated in Fig. 1.

There are 64 possible combinations of dots and their configurations. This allows for encoding all letters of the alphabet, including characters of letters specific for a particular language, as well as all diacritical marks.

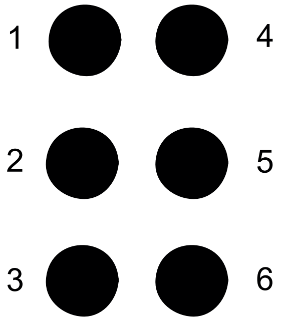

Fig. 1. Braille six-dot cell

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Embossed prints are read in a tactile way, using the fingertips. Direction of reading is the same as in the case of the Latin alphabet, i.e. from left to right. Each finger covers the area of a single character and in the reading process both hands are involved (fingers of the dominant hand are responsible for recognition of the letters, whereas fingers of the other hand search for successive characters, words or lines of the text).

The Braille alphabet is the most popular system of embossed writing. In many countries blind pre-school children are introduced to embossed print, even before they get to know particular letters of the alphabet [6]. It is done by labeling objects of everyday use , or using e.g. special set of books with fairy tales, with written text and embossed inscriptions which can be simultaneously read by a minder and a blind child [7].

However, due to a variety of developments in media technologies, this form of reading for the blind and the visually impaired is currently partially superseded with other forms. The use of audiobooks read by a reader or a speech synthesizer in place of books printed in embossed writing became common, as are systems aiding the blind in moving around unknown environments [8, 9]. Nevertheless, the application of Braille in teaching aids (descriptions of diagrams, graphs), information prints, descriptions of objects, maps and plans of buildings, etc. still remains very important.

2.1. The most popular methods of making embossed printouts

2.1.1. Embossing of the dots. One of the most popular methods of making embossed printouts is by pressing out the dots in a paper matrix. The convex shapes of Braille dots in the paper are made with special dies. The method is used both for making a single copies of documents, as well for printing books (then, a whole page is embossed at one time by means of a matrix with convex characters).

The typical printing devices for home use are still expensive, however with governments' and charity foundations' financial assistance, they become more accessible to the blind. There are also individual attempts to design low-budget devices, e.g. embosser of Lego® blocks built by a 12 year old boy [10].

2.1.2. Copying on microencapsulated paper. In this method, to obtain an embossed copy, special microencapsulated paper, is used together with a computer, standard printer and copying machine. The first step is to prepare a text or an image, which is to be embossed as a line art or a gray scale print. Next, the printout is fed to the copying machine and driven by feeding rollers. Light from an illuminator is directed by a reflector onto the surface of a sheet of paper, as illustrated in Fig. 2. The light emission is mostly absorbed in places where the paper is blackened, causing their embossing, while in the other (not blackened) places the ray absorption is too small to cause a growth of the microcapsules. Compared to the press out method copying on microencapsulated paper has many advantages. Printouts made by this method are much more durable, and it is much easier to make graphical images (e.g. plans of buildings).

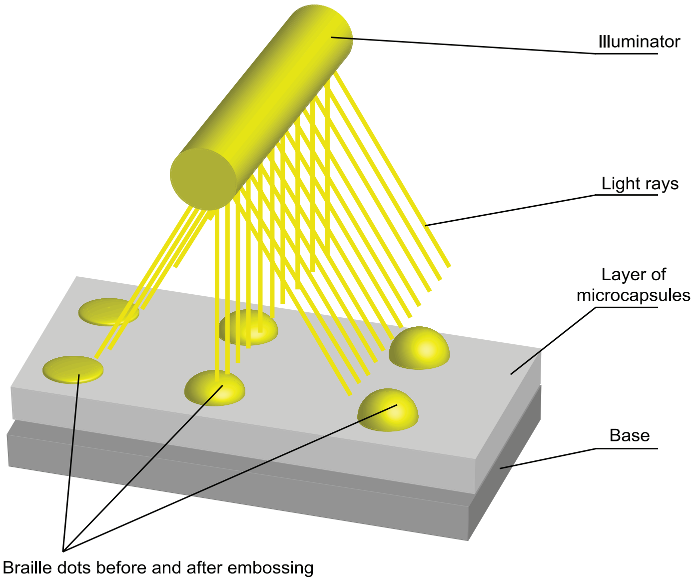

Fig. 2. Process of embossing the microencapsulated paper

However, the method allows for arbitrary selection of the size of the convex characters and an inexperienced user may easily choose an unsuitable type size. The copying process itself has limited repeatability As a result, the created copies can differ greatly, to the extent that the embossed text may not be readable to a blind person.

There exist also other methods of making convex printouts, e.g. screen printing (often used for tagging drugs), thermal forming of films on a prepared matrix (used most often in the case of convex graphics in large editions) or convex ink printing (deposition of a dense ink onto a PVC base by means of jets positioned within a plane) [11].

Very important is to determine the influence of abrasion on durability of the Braille dots (especially height) [12].

2.2. Parameters of the Braille characters. The Braille alphabet has been used for over 150 years, and its technical parameters are now partially standardized (Fig. 3).

However, those standards vary for different countries. For Italian Writing the diameter (d) of the dot is set to be 1.0 millimeter while it is 1.6 millimeter for American Standard Sign.

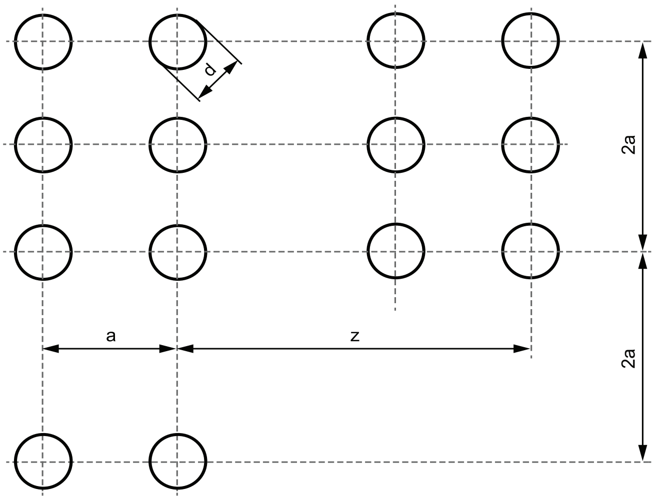

Fig. 3. Geometric parameters of the embossed characters

The size of diameter (d) determines the other dimensions, as presented in Fig. 3 (the larger the dot diameter, the higher values of parameters a and z). There are also large differences in the recommended height (h) of the dots (Fig. 4). Generally a height (h) of 0.5 millimeter is recommended, however, e.g. in France it is 0.6–0.9 millimeter, and in Sweden 0.25 millimeter. In practice, height of the dots depends strongly on the method of making the printout, whereas manufacturers have an interest in establishing the minimal height of the dot which is necessary for the text to be readable by the blind [13], because it is technologically easier to make dots which are less embossed.

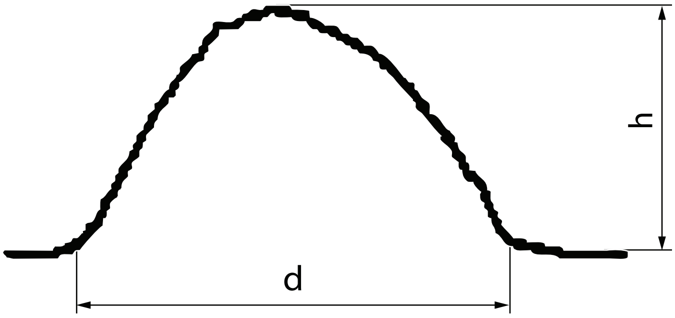

Fig. 4. Cross-section through an embossed dot

Over the last years, as new methods of making convex printouts were introduced, the blind started to pay more attention to an important feature of convex writing, namely the roughness of the surface that is to be touched. The issue of tactile sensing is quite individual and depends on the distribution of receptors over the finger [14], and to determine whether something is pleasant while touched is very subjective, although a defined scale is proposed [15]. Surface roughness is not the most important factor in deciding whether a text is readable, but the blind are often afraid that surfaces are too rough and that it can cause hardening of their finger tips decreasing their tactile sensitivity.

Because of the fact that the blind often complain that it is difficult for them to read convex printouts, it was decided to carry out a study related to the quality of characters in Braille writing prints. The study had two stages: in the first, sample printouts were created and chosen parameters of the Braille characters were evaluated. In the second, the embossed inscriptions were assessed by the blind, who determined their quality.

3. The studied parameters

Taking into consideration the outcome of the consultations with the blind, and opinions of the preparers of convex printouts and the conclusion of the initial study [16], it was decided that the investigation will be based on parameters having the following values:

- height (h) of embossed dot: values of 0.3, 0.6 and 0.9 millimeter,
- diameter (d) of embossed dot: 1.2, 1.4 and 1.6 millimeter,
- roughness – two values of Ra parameter related to the accepted method of making the samples.

One used also other values: based on dimensions of Marburg Medium Sign (in case of diameters 1.2 and 1.4 millimeter) or Marburg Large Sign (in case of diameter 1.6 millimeter).

18 samples (complete combination for 3 values of height, 3 of diameter and 2 of roughness) were prepared for studies of the quality of convex characters. Randomly generated strings of characters were used In the first tests. However, it was not accepted favourably by the evaluators. For this reason a Polish Word was selected for each sample. The words were similar with respect to how difficult it is to read them and how frequently they appear in Polish language [17]. The full set of the samples along with the parameters is presented in Table 1.

Table 1
Set of text samples with the related parameters

No.	Polish Word	English Translation	Height h [mm]	Diameter d [mm]	Roughness
1	teatrzyk	theater	0.3	1.8	larger
2	aktorski	drama	0.3	1.4	larger
3	listonosz	postman	0.6	1.6	larger
4	fotograf	photographer	0.3	1.8	smaller
5	urodziny	birthday	0.9	1.4	larger
6	poddasze	garret	0.3	1.4	smaller
7	dokładny	accurate	0.6	1.6	smaller
8	mieszany	mixed	0.9	1.8	larger
9	składnik	component	0.6	1.4	larger
10	pływanie	swimming	0.9	1.6	larger
11	garnitur	suit	0.9	1.8	smaller
12	lotnisko	airport	0.9	1.4	smaller
13	dobrobyt	welfare	0.9	1.6	smaller
14	ulubiony	favorite	0.6	1.8	larger
15	prysznic	shower	0.6	1.8	smaller
16	zbrodnia	crime	0.3	1.6	larger
17	czerwony	red	0.3	1.6	smaller
18	kapelusz	hat	0.6	1.4	smaller

3.1. Method of making of the samples. In order to make samples with embossed Braille letterings, it was necessary to select a method, that would guarantee the following:

- repeatability in making several copies,
- fastness – lack of shape changes, when read a few times,
- option of changing the range of parameter values,
- option of using bases with differing roughness.

None of the methods designed for making printouts for the blind meet all the specified requirements. Methods that ensure repeatability of the printouts do not allow varying values of the parameters related to the dot diameter and the spacing between the dots. On the other hand, methods that make it possible to change the parameters, do not ensure repeatability of the printouts (e.g. in the case of printouts on microencapsulated paper various diameters of the dots are observed, even within one page).

In this study, two methods of fast prototyping were used: PolyJet [18] and selective laser sintering (SLS) [19]. Fast prototyping methods are commonly used in design or in medical technologies [20]; in a not distant future they will become available for an ordinary user. Application of these methods made it possible to obtain samples that meet the specified requirements, and also to assess their usefulness in making embossed prints for the blind. A design of the samples (Fig. 5) was prepared using the Autodesk Inventor software, which accommodates the required values of the parameters.

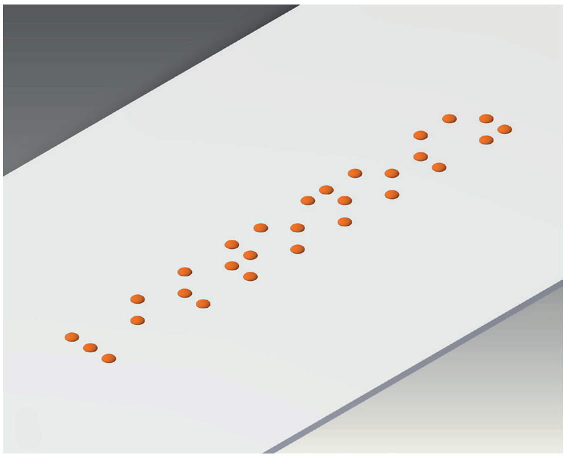

Fig. 5. Design of the sample with Braille characters

Samples with dimensions of about 120 × 50 millimeters and thickness of 1 millimeter were made. While printing, it was taken care of setting such position of the sample that ensures obtaining a possibly smooth upper surface, which was a background of the embossed characters.

To control repeatability, the selected samples were assessed by measurements of parameters using a contact method (profilometer and contour measuring instrument) and a contact-less one (method of fringe projection). Two different methods of 3D printing made it possible to obtain surfaces of various roughness.

4. Measurements of the parameters

In order to perform measurements which aimed to confirm repeatability of sample making, and also to determine by how much the obtained values differed from preset ones, three specimens of each sample were made using one of the two chosen 3D printing technologies. The measurements were performed using: Tylor Hobson Form Talysurf PGI 930 (measurement of roughness Ra), Mahr Perthometer PCV (measurement of height and diameter of the dots), and a measurement assembly (based on the fringe projection method) developed at the Institute of Micromechanics and Photonics, Warsaw University of Technology (measurement of height and diameter of the dots). The measurement procedure consisted of repeated (ten-times) measurement of a given parameter (in different places on the surface) in each of the 3 sample specimens. The data collected were sufficient to evaluate the results using statistical methods of analysis.

4.1 Results of measurements using the contact method. Statistical analysis of the results consisted of:

1. verification whether distribution of the results in a series of measurement has characteristics of a normal distribution (using c^2 test, Shapiro-Wilk test, and Kolmogorov-Smirnov test) (Table 2 and Table 3)
2. verification whether differences between specimens of one sample are statistically significant (using Least Significant Difference (LSD) test)

Table 2
Normality test related to distribution of results and statistical significance for 3 specimen of one sample made according to SLS method ("+" means yes, "–" means no)

	χ^2 Test			Shapiro-Wilk Test			Kolmogorov-Smirnov Test			Differences*
Roughness Ra	+	+	+	+	–	+	+	+	+	–
Height h	+	+	+	+	+	+	+	+	+	–
Diameter d	+	+	+	–	+	–	+	+	+	–

* Are the differences statistically significant (on the basis of the LSD test)

Table 3
Normality test related to distribution of results and statistical significance for 3 specimen of one sample made according to PolyJet method

	χ^2 Test			Shapiro-Wilk Test			Kolmogorov-Smirnov Test			Differences*
Roughness Ra	+	–	+	+	–	+	+	+	+	+
Height h	+	+	+	+	+	+	+	+	+	–
Diameter d	–	+	–	–	–	+	+	+	+	+

* Are the differences statistically significant (on the basis of the LSD test)

Statistical inference on the basis of the LSD test can be regarded correct, only when the condition of normality of the distributions of the results is confirmed. Only in the case of height (h) measurement results, all the tests indicate normality of the distribution. The Kolmogorov-Smirnov test, which is the least sensitive, indicated normality of the distribution in all the series of measurements. However, the χ^2 test being more sensitive and the most sensitive Shapiro-Wilk test indicate deviations from the normal distribution. Nevertheless, the LSD test was performed, to determine if there are statistically significant differences between particular series of measurement (successive specimens of the samples). It was also analyzed whether the existing differences can influence an outcome of the studies, i.e. whether a significant deviation from an preset value can influence the assessment (e.g. qualifying a sample to be smooth, even if it has some degree of roughness).

The analysis that was carried out indicated that differences between particular specimens are small enough not to influence assessment of the quality by the blind. This is presented in

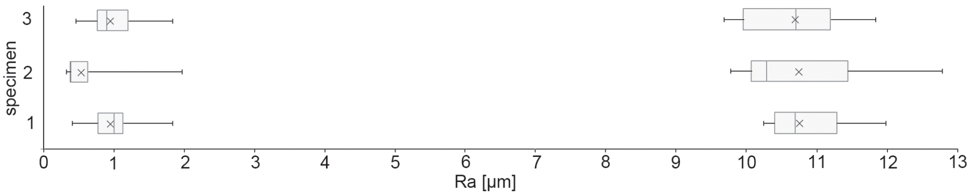

Fig. 6. Comparison of plots of measurement series of Ra parameter

Fig. 6 by comparing two measurement series of Ra parameter for samples made using PolyJet method (on the left) and SLS method (on the right).

The main aim in doing these series of measurements was to determine repeatability of the test samples. Table 4 lists average values for each specimen of the sample, together with respective 2σ values, i.e. value of twofold standard deviation, which is a measure of repeatability. Assumption of no systematic errors makes it possible to take the standard deviation as the measurement of uncertainty.

Table 4
Comparison of the results against the uncertainty of measurement (3 specimen)

		Ra [µm]		Diameter [mm]		Height [mm]	
		Mean Value	2σ	Mean Value	2σ	Mean Value	2σ
SLS	S. #1	10.75	1.35	1.573	0.1	0.791	0.1
	S. #2	10.73	1.92	1.592	0.06	0.768	0.08
	S. #3	10.68	1.72	1.578	0.06	0.701	0.13
Poly-Jet	S. #1	0.94	0.62	1.819	0.03	0.539	0.006
	S. #2	0.53	0.5	1.794	0.03	0.538	0.008
	S. #3	0.94	0.59	1.844	0.04	0.54	0.004

The measurement uncertainties for evaluation of height (h) and diameter (d) of embossed dot allow a conclusion that the making of the test samples was repeatable, and there was no problem in distinction between samples with preset parameter value e.g. samples with dot's height (h) of 0.3 millimeter, and 0.6 millimeter.

The value of roughness had not been preset when making the test samples. However, the methods of making the samples themselves were selected to produce two very different values of surface roughness. The approach was successful. Samples with little roughness had, a Ra parameter of about 1 micrometer, and for those with a high degree of roughness, Ra was approximately 11 micrometers. Relatively large measurement uncertainty did not preclude differentiation between rough and smooth samples.

4.2. Measurement using the contact-less method. The method of fringe projection consists of analysis of a fringe image projected onto a surface of the studied object. As a result of scanning an object, a so-called cloud of points is obtained, i.e. a set of points lying on the scanned surface. The recorded 3D image of the studied sample is analyzed using dedicated software and distances between points in the cloud calculated, allowing in this case to determine height and diameter of dots constituting a Braille character.

The method should have a theoretical measurement uncertainty even of about 0.1 micrometer, due to very high resolution of the captured image, but the available systems have an uncertainty factor of 5 micrometers, thus making them useless for measuring surface roughness.

Therefore, this method was used only for verification of measurements obtained with the contact method, and height and diameter parameters for a single sample were measured (see an example: Fig. 7).

Again as in the case of the contact method (profilometer), 2σ value was chosen as a measure of repeatability of making the samples. The presented values (Table 5), and also specificity of the study, allow the conclusion that this method can be considered as suitable for measuring height and diameter of Braille dots.

Table 5
Comparison of the results

	Diameter [mm]		Height [mm]	
	Mean Value	2σ	Mean Value	2σ
SLS	1.595	0.07	0.69	0.07
PolyJet	1.75	0.15	0.52	0.07

The method of fringe projection is also extremely practical in assessment of the quality of convex characters because it is possible to scan an area with several letters of the Braille alphabet (contained in a single cloud), thus making it possible to measure parameters for a number of Braille dots without the necessity of performing separate scans.

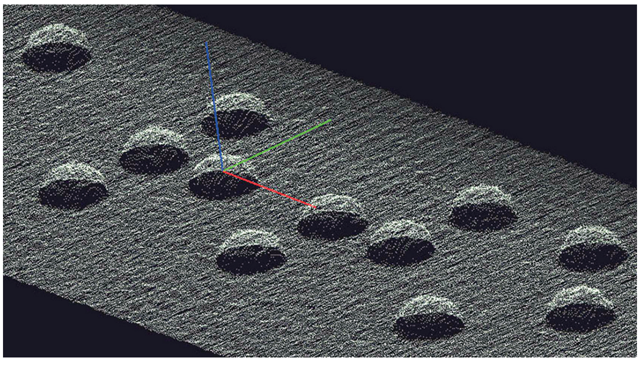

Fig. 7. Point cloud obtained as a result of scanning the sample using the method of fringes projection

5. Assessment of the quality of the samples by the blind

5.1. Methodology of the study. 18 test samples were prepared for the study. The tested samples were assessed by 48 blind persons, who can read Braille (proficiency in reading was not required, since a convex text that is property made should be easy to recognize even by individuals who still learn tactile reading. In order to reduce the effect of fatigue and vacillation of the assessing person, each person assessed a set of 6 samples for general quality of the text (assessment of the full set of 18 samples was considered to be too wearisome). Assessment of the quality consisted of arranging the samples in order from worst quality to the best. Additionally, the blind were asked to separate the samples into 3 groups: of bad, acceptable and good quality in order to determine a set of parameters, for which the quality of the printout is graded to be "the best" or "acceptable".

Care was taken to ensure that the experiment is balanced and orthogonal. It was achieved through an equal number of assessments for each level of a factor (balancing) and equal frequency of occurrence of a given combination of levels (orthogonality).

The assessing blind persons were divided into two age groups. The first group included students (14–17 years old), and the second included persons 60+ years old. In each group, the number of women and men was the same. The participation in the studies was voluntary and anonymous. The authors of studies obtained an oral consent of minors' parents and the written consent of the school's headmaster.

Table 6.
Tests of Between-Subjects effects

	Sum of Squares of III Type	No. of D. F.	Mean Square	F-statistics	Significance	Partial η^2
Corrected Model	377.000 (a)	17	22.176	12.932	<0.0001	0.449
Constant	3528	1	3528	2057.365	<0.0001	0.884
Height	165.812	2	82.906	48.347	<0.0001	0.264
Height* Roughness	79.396	2	39.698	23.15	<0.0001	0.146
Height* Diameter	36.875	4	9.219	5.376	<0.0001	0.074
Roughness	32	1	32	18.661	<0.0001	0.065
Diameter* Roughness	28.938	2	14.469	8.438	<0.0001	0.059
Height* Diameter* Roughness	18.542	4	4.635	2.703	0.031	0.039
Diameter	15.438	2	7.719	4.501	0.012	0.032
Error	463	270	1.715			
Total	4368	288				
Corrected Total	840	287				

(a) $R^2 = 0.449$ (corrected $R^2 = 0.414$)

The quality of a sample with inscription (called also "a plate") was evaluated using two methods of assessment:

1. Rank assessment is a relative assessment of a plate in comparison to other plates in a studied set. The following gradation was used: from a grade 1 (plate that has been assessed as the worst in the set) to grade 6 (plate that has been assessed as the best in the set). This assessment does not determine unequivocally the absolute quality of a plate (grade 6 plate can still be regarded as a bad quality plate), due to its 6 level gradation the rank assessment was considered more useful, and the presented analysis of factors and their interactions is based on this assessment.
2. Absolute assessment of the quality (with three assessment levels: 1 – bad, 2 – acceptable, 3 – good). This is a qualitative assessment, which was used to determine an acceptable quality of a plate.

5.2. Analysis of the assessment results. In order to determine the influence of particular factors and factor interactions on the quality of Braille printing, analysis of variance (ANOVA) was carried out.

Table 6 presents analysis of significance values for the main effects and their interactions. Calculations indicate that in order to determine an optimal combination of parameters all the effects should be taken into consideration (significance of all factors is lower than 0.05). The height (h) parameter has the strongest effect, then interactions of the height (h) and roughness then height(h) and diameter (d).

Analysis of influence of particular factors and interactions was done using the Bonferroni test.

The influence of a person's age and sex on assessment of the quality of convex printouts was also studied (Table 7). The analysis used the rank scale (in order to check significance of the influence of interactions of the main factors with the factors of age and sex) as well as the absolute scale (in order to determine influence of the factors of age and sex on assessing the sample to be "acceptable" or "good"). Analysis of the "rank scale" and "absolute scale" assessments may give different estimates due to differences in the amount of data available. In the case of rank assessment the assessing persons always arranged the plates from the worst to the best one, i.e. each of 6 levels was determined. In the case of absolute assessment, it could happen that the blind assessed all the tested samples to be of the same quality (e.g. "bad"). In effect the number of sample plates available in each level of assessment can be very different.

The analysis consisted of performing tests on the inter-object effects for the following factors: height, diameter, roughness and the interactions of these factors with the factors of age and sex. The tests indicated significance of interaction between sex and diameter only. Other effects are not statistically significant. A post hoc type test was used to investigate this dependence, and confirmed that the size of diameter (d) significantly influenced assessment by men who had taken part in the study. No such effect has been observed in the women's group. Due

Table 7
Tests of Between-Subjects effects

	Sum of Squares of III Type	No. of D. F.	Mean Square	F-statistics	Significance	Partial η^2
Corrected Model	246.411 (a)	17	14.5	6.6	<0.0001	0.29
Constant	3528	1	3528.0	1604.7	<0.0001	0.86
Height	157.787	2	78.9	35.9	<0.0001	0.21
Diameter	15.846	2	7.9	3.6	0.03	0.03
Roughness	32.012	1	32	14.6	<0.0001	0.05
Age	0	1	0	0	1	0
Height *Age	10.562	2	5.3	2.4	0.09	0.02
Diameter *Age	0.146	2	0.1	0	0.97	0
Roughness *Age	0.5	1	0.5	0.2	0.63	0
Sex	0	1	0	0	1	0
Height *Sex	3.856	2	1.9	0.9	0.42	0.01
Diameter *Sex	14.502	2	7.3	3.3	0.04	0.02
Roughness *Sex	3.608	1	3.6	1.6	0.2	0.01
Error	593.589	270	2.2			
Total	4368	288				
Corrected Total	840	287				

to a lack of a study proving significant differences in tactile perception of women and men, such correlation should be investigated among a larger group of evaluators.

6. Results

The rank assessment made it possible to distinguish samples that were evaluated the Best, what enabled determination of values of the parameters that are preferred by the blind (Table 8).

Results of this study may provide some guidelines for making eligible embossed print for the blind. This should be useful for manufacturers of devices making embossed prints and for those, who operate such devices.

In the frame of these investigations, that is, on the basis of the experiment and the assessment of the quality, performed by the group of the blind, it was possible to formulate guidelines to be observed if an eligible embossed text is to be prepared:

- rank "the best" was assigned to samples with the following parameters: height h = 0.9 mm, diameter d = 1.6 mm, roughness Ra ≈ 1 μm

Table 8
Values of parameters preffered by the blind

No.	Height h [mm]	Diameter d [mm]	Roughness	Mean value of the rank assessment
1	0.9	1.6	smaller	5.313
2	0.9	1.4	smaller	5.063
3	0.6	1.8	larger	5.063
4	0.6	1.8	smaller	5
5	0.6	1.6	smaller	4.563
6	0.9	1.8	smaller	4.25
7	0.6	1.4	smaller	4.188
8	0.9	1.8	larger	4
9	0.3	1.6	larger	3.313
10	0.6	1.4	larger	3
11	0.9	1.6	larger	2.938
12	0.3	1.8	larger	2.688
13	0.9	1.4	larger	2.563
14	0.6	1.6	larger	2,5
15	0.3	1.4	larger	2.438
16	0.3	1.4	smaller	2.188
17	0.3	1.6	smaller	2.125
18	0.3	1.8	smaller	1.813

- rank "good" was assigned to samples with the following parameters:
  - h = 0.9 mm; d = 1.4 mm; Ra ≈ 1 μm
  - h = 0.6 mm; d = 1.6 mm; Ra ≈ 10 μm
  - h = 0.6 mm; d = 1.6 mm; Ra ≈ 1 μm
- for older persons, the critical parameter is the height (h); it is unlikely that a printout with a dot height of 0.3 millimeter will be assessed as a good one,
- surface roughness affects the readability of embossed printout; a smooth surface is assessed to be more suitable than a coarse one.

7. Summary

The study is the first one which apart from measuring the effect of the usual parameters of embossed writing (i.e. height (h) and diameter (d) of the dots), investigated also the role of surface roughness, which is a very important issue for the blind. Degree of surface roughness is often not decisive in rating a print to be readable, however if the surfaces are too rough, the blind shun reading such text as they are afraid of damaging and hardening the fingertips, and decreasing their tactile sensitivity.

In studies like these, it is of utmost importance to select an appropriate group of persons assessing the convex inscriptions.

Within the reported studies, this assessment was performed not only by individuals, who can read Braille text proficiently but, more importantly, by individuals, who can barely read it, using Braille only for simple tasks like identification of a medicine. Such individuals will probably constitute, in future, the majority of Braille users.

The approach used in these assessments of convex characters in the Braille alphabet can be applied in general to any of the methods of making convex printouts, and parameter measuring techniques.

Within the studies, the materials used to produce samples by the rapid prototyping method differed from the commonly used one in making printouts for the blind. The subsequent investigation confirmed that they were fully acceptable by the blind. In future, it is planned to expand the studies by producing test samples made of traditional materials too. Making a sample using a traditional method, and measuring its parameters, and then producing a sample in 3D printing with the same parameters, would allow assessment of the effect of the base material on tactile sensing of the Braille reader.

In future research, the intention is to continue assessment of the fringes projections method for measuring embossed test samples. This method is inadequate for measuring surface roughness (high uncertainty of measurement), but is very convenient in the determination of the shape of a single dot, because it provides 3D images.

Another important factor in such studies is information about the assessing person, e.g. for how long he/she has been blind or how well he/she mastered reading convex printouts. This will require carrying out extended studies in co-operation with other centers for the visually impaired, to gather a suitable pool of statistical data.

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