Variability of stamp impression measurements under different apposition conditions

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Abstract

When a forensic document examiner obtains differences in size measurements between a questioned and reference stamp impressions, it may be difficult to assess whether such findings might be due to the use of the same stamp in different apposition conditions or are due to the use of different stamps. To address this issue, the present work has studied the variability of size measurements of stamp impressions apposed in various (pressure, humidity and temperature) conditions. Different stamps were also used to evaluate the influence of the fabricant, the matrix (photopolymer or rubber) and the inking type (self-inking and handstamp). While statistical tests sometimes indicated differences in the results, the measurement distributions overlapped for all kind of conditions (same stamps, different stamps), except for the two stamps produced by different manufacturers. Based on the findings of this study, a difference above 0.09 cm would support the hypothesis that two different stamps were used to produce the impressions. However, size differences below 0.09 cm were also encountered for impressions made using different stamps. The maximal size difference was actually measured for two stamps produced by different manufacturers (up to 0.29 cm).

Keywords: Questioned documents, stamp impressions, size measurements, intra and inter-variability, environmental and apposition conditions.

1. Introduction

Despite the increase in purely digital documentary transactions, stamps are still regularly encountered and challenged in practice. Indeed, they are still routinely used in many administrative processes as seals on official documents (1-6). When challenged, these documents may be part of an expertise and, to assess the authenticity of the latter, the printing of a stamp may then become the subject of comparison with authenticated reference documents (7,8).

A case example could be a lease contract that contains a stamp impression included in the signature of the building owner. If the authenticity of the contract is questioned by the lessor, the contract would then be subjected to a forensic examination to assess its authenticity. Several elements (paper, ink, signatures) could be examined more precisely, including the stamp impression (the so-called *questioned stamp impression*). The latter would be analyzed and compared with impressions from the known *reference stamp*. These may include other authenticated lease contracts on which the same stamp has been printed or the stamp used by the complainant could be obtained directly to make comparative impressions. While the ink might optically or chemically be characterized (2,3,5), the physical features might also be compared (7). According to the American Society for Testing and Materials (ASTM), two types of characteristics are then analyzed and compared: class characteristics, such as the size and image of the stamp; and individual or particular characteristics, such as defects that are produced due to the use of the stamp (9,10).

If no particular characteristics can be detected, but class characteristics measurements (i.e. size) yield very slight differences between the questioned stamp (on the questioned document) compared to the impression of the reference stamp (e.g. less than one millimeter), then the question arises whether this difference can be expected if the questioned stamp impression was made with the same stamp (the size difference would be due to the so-called intra-variability), or whether this difference would support the hypothesis that two different stamps were used (i.e. the size difference would be due to the so-called inter-variability).

While possible influence of the type of paper and ink quantity on the size of stamp impressions have been previously mentioned (8,9), only one study explored the influence of environmental conditions on the size of stamp impressions (7). The influence of temperature and humidity has been explored, indicating size differences up to 2 mm after 1 month. In order to further investigate and characterise the conditions that might influence stamp size impressions, the present work aimed at evaluating the differences in the measurements obtained for impressions made with the same stamp under different conditions (i.e., intra-variability), as well as for impressions made using different stamps with the same pattern (i.e., inter-variability). Thus, stamps from different manufacturers, made with different matrices (photopolymer and rubber) and using different apposition systems (hand and self-inking) were purchased for this study. The influence of applied pressure, humidity, temperature and time were tested. A systematic study of these parameters was carried out to determine the size differences that can be expected if impressions were made with the same stamps under different conditions, compared to the measured variation for impressions made using different stamps. Thus, obtained results will give an indication whether size measurements are useful for comparison of stamp impressions in practical caseworks.

2. Material and methods

2.1. Material

Five different stamps were ordered from two manufacturers as described in Table 1. Two types of application were selected: hand (Figure 1) and self-inking (Figure 2). The stamp application matrix was made of photopolymer (P) or rubber material (R) (Figure 3). The pattern used in this work was created to have several precise measurement points and several shapes (straight lines, squares, circle, and writings). Small lines have been placed in the pattern to ease measurements (see Figure 3 and 4).

Manufacturer	Stamp type	Matrix materials	Abbreviation
Manufacturer 1 (Allegra GmbH, Luzern)	Wooden stamp	Photopolymeric	WP1
Manufacturer 2 (Multi Timbres, Lausanne)	Wooden stamp	Photopolymeric	WP2
	Wooden stamp	Rubber	WR2
	Self-inking stamp	Photopolymeric	SP2
	Self-inking stamp	Rubber	SR2

Table 1 - Summary of the material and abbreviations used in this work

As required by manufacturer 1, the model was sent in .eps format with a resolution of 600 dpi. This format contained the vector data of the image. While the stamp matrix measured 4 x 4 cm as requested, the pattern was slightly smaller 3.8 x 3.8 cm (see Figure 3). For manufacturer 2, the model was sent in .jpeg format with a resolution of 600 dpi. While the vectorization of the pattern was not transmitted, the final size of the image was indeed 4 x 4 cm as requested. The ink of all type of stamps was water based.

Figure 1 - Hand wooden stamp (W)

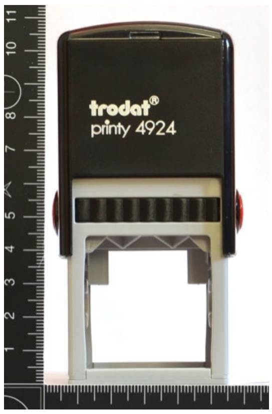


Figure 2 - Self-inking stamp (S)

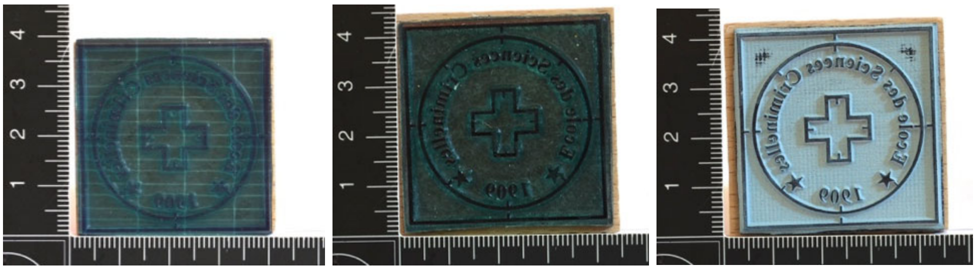


Figure 3 - Left: photopolymer matrix from manufacturer 1 (WP1); Center: photopolymer matrix from manufacturer 2 (WP2); Right: rubber matrix from manufacturer 2 (WR2).

2.2. Apposition of the stamp impressions

The stamp impressions were applied by the same person on A4 Xerox copy paper within a grid printed using a laser printer. 36 impressions per experiment were made (this corresponds to three sheets per experimental condition). After the appositions, the sheets were scanned at a resolution of 600 dpi to obtain a sufficiently high resolution to carry out the measurements. Higher resolutions were also tested, but no added value could be demonstrated.

2.3. Size measurements of the stamp impressions

Six measurements were made by using Adobe® Photoshop® CS 6 (version 13.0.6 x64) using the *ruler tool* (Figure 4) to take into consideration the influence of different angles and distances on the variability of the measurements. Mean and absolute errors were calculated to estimate relative standard deviation.

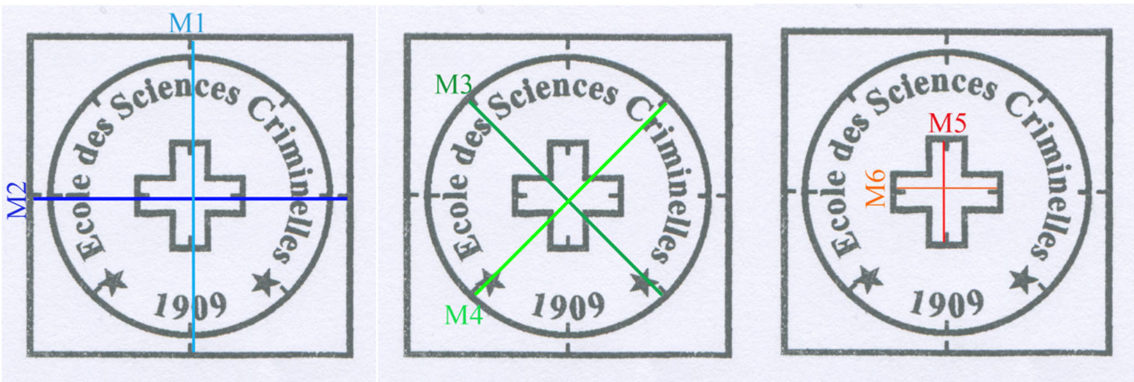


Figure 4 - Illustration of the six measurements M1 to M6 made on stamp impressions

2.4. Experiments

Reproducibility of measurements

Mean, absolute error and relative standard deviations (RSD) were measured for all stamps using the measurements taken on 36 stamp impressions made in standard conditions. This allowed evaluating the size intra-variability for each stamp and measurement.

Comparison of stamps of different types

The following experiments were made in a conditioned laboratory (ca.30% of relative humidity and 22°C ± 1°C) in order to evaluate size differences between the stamp impressions made (see Table 1):

• by different stamp matrices from manufacturer 2 (polymer and rubber)

- comparisons between impressions made with stamps WP2 and WR2
- comparison between impressions made with stamps SP2 and SR2

• by different stamp types from manufacturer 2 (wood and self-inking)

- comparisons between impressions made with stamps WP2 and SP2
- comparisons between impressions made with stamps WR2 and SR2

• by different wood stamp manufacturers (1 and 2)

- comparisons between impressions made with stamps WP1 and WP2

These experiments aimed to determine which measurement differences are induced by the use of different stamps (inter-variability).

Influence of applied pressure

Impressions were made using two wooden stamps, one with photopolymer and the other with rubber matrix (WP2 and WR2). With each of these stamps, 36 impressions were made using a high pressure and 36 using a very low pressure. The applied pressure was not measured, but assessed by the operator (see example in Figure 5).

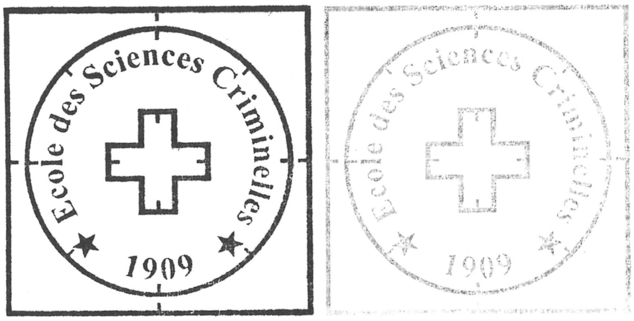


Figure 5 – Stamp impressions made with high and low pressure (WR2).

Influence of humidity

To evaluate whether the exposure of the paper or the stamp to high humidity at the time of stamping has an influence on the size of the impression, several experiments have been performed using the wooden stamps WP2 and WR2. It was decided to start the experiments at a very high humidity (i.e. 80% relative humidity) in order to evaluate the influence of extreme conditions on the size of stamp impressions. Thus, the sheets of paper and the stamps were stored at 80% humidity and 23 °C in a climatic chamber for a minimum of 12 hours (Weiss Technik, Switzerland). Then, the impressions were made in a room kept at the same humidity and temperature conditions. Finally, the sheets with the impressions were scanned in the same room (with a paper still humid) or in a room kept at normal conditions for another 12 hours (with a dried sheet of paper at ca. 30% RH). Obtained results were compared to impression size measured at ambient conditions.

Influence of temperature

To analyze the influence of relatively low and high (but realistic) temperatures, two sets of experiments were carried out using the wooden stamps WP2 and WR2:

- Experiments at 5°C and 20 % humidity: the stamps were cooled down during one hour using the climatic chamber. Then the impressions were immediately made under ambient conditions. To keep the stamp cold, it was put back in the climatic chamber for 5 minutes after twelve appositions.
- Experiments at 50 °C and 30% humidity: the stamps were heated in the climatic chamber for one hour and the same deposition procedure was followed than for cold stamps.

Influence of time

Finally, it was evaluated whether the time between apposition and measurements had an influence on the size measurements. For this, the sheets with the impressions of the wooden stamp with the rubber matrix (2 WP and WR2) were rescanned again after one year. During this time, the leaves were stored in a plastic cover in a file at ambient conditions. Moreover, new stamp impressions were also made one year later to see if the stamp matrices were modified during the storage. The stamps were stored in a box at ambient conditions and the impressions were made in the same conditions.

2.5. Statistical treatments

R studio (version 3.2.2) and *Microsoft Excel* (Professional Plus 2010) were used for data treatments. The normality of the data was tested using a Shapiro test (11). This test is based on a regression by a quantile-quantile plot, as well as the variance of the data. Both estimates are close when the data follow a normal distribution. Obtained p-values were compared to tabulated values. The confidence interval was set at 95%. Thus, if this obtained p-value was lower than the tabulated value for a limit of 0.05, it meant that the data did not follow a normal distribution. It turned out that the data obtained in this work did not follow a normal law.

The Wilcoxon test was, therefore, selected to assess whether a significant difference between two groups existed, using ranks, as it applies to non-normal data (12). The 95% confidence interval was also set and when the p-value obtained was inferior to the tabulated value, the difference was considered significant. The test was performed for each measurement separately to assess whether the difference could be significant for some measurements and not for others (for example in the case of a lateral or vertical expansion of the pattern). The obtained results were then discussed in a forensic perspective.

3. Results and discussions

3.1. Measurements reproducibility

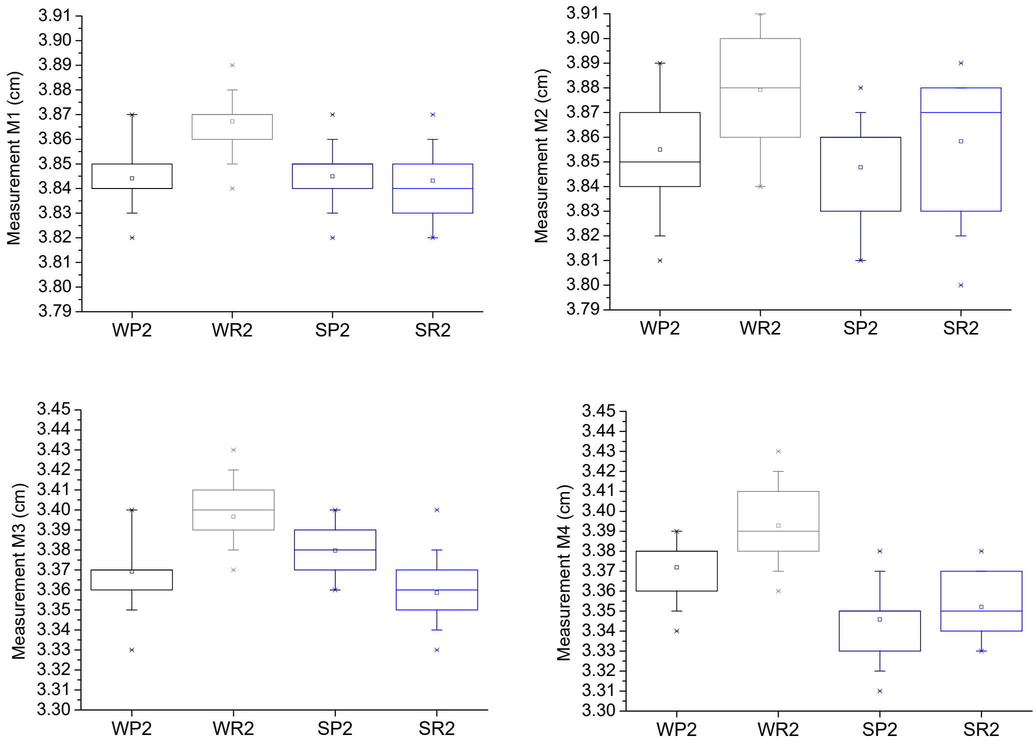
In order to evaluate the size intra-variability, mean, absolute error and RSD values were calculated using replicate measurements of 36 stamp impressions made by the same stamp in the same conditions. The mean absolute error ranged from 0.008 cm (for measurement M5 of the stamp SP2) to 0.026 cm (for measurement M2 of the stamp SR2). Absolute errors were higher for the horizontal measurement M2, which showed also the largest difference measured between two stamp impressions with a value of **0.09 cm** (for stamps WP1 and SR2). This is the highest absolute difference that was measured between two impressions made with the same stamp. RSD values were generally higher for the smaller measurements M5 and M6 and reached up to 1.06% (see Table 4).

Measurement (cm)	**WP1**	**WP2**	**WR2**	**SP2**	**SR2**
M1	3.648 ± 0.015 (0.41%)	3.844 ± 0.013 (0.34%)	3.867 ± 0.011 (0.28%)	3.845 ± 0.011 (0.27%)	3.844 ± 0.013 (0.34%)
M2	3.657 ± 0.025 (0.67%)	3.855 ± 0.023 (0.60%)	3.879 ± 0.022 (0.56%)	3.848 ± 0.022 (0.56%)	3.859 ± 0.026 (0.68%)
M3	3.181 ± 0.015 (0.46%)	3.369 ± 0.016 (0.48%)	3.397 ± 0.014 (0.42%)	3.359 ± 0.015 (0.45%)	3.379 ± 0.013 (0.38%)
M4	3.196 ± 0.012 (0.38%)	3.372 ± 0.015 (0.44%)	3.393 ± 0.013 (1.04%)	3.346 ± 0.017 (0.51%)	3.352 ± 0.015 (0.43%)
M5	1.163 ± 0.010 (0.89%)	1.222 ± 0.013 (1.06%)	1.231 ± 0.013 (1.04)	1.216 ± 0.008 (0.60%)	1.223 ± 0.012 (0.95%)
M6	1.157 ± 0.012 (1.03%)	1.222 ± 0.013 (1.04%)	1.232 ± 0.012 (0.97%)	1.214 ± 0.009 (0.72%)	1.222 ± 0.012 (0.98%)
Maximal differences	0.09	0.08	0.07	0.07	0.09

Table 4 – Mean, standard deviation and relative standard deviation (%) for replicate measurements made on 36 stamp impression (in cm). Maximal differences between two stamps impressions were also indicated. The largest differences of 0.09 were obtained for measurement 2.

3.2. Comparison of stamps of different types

Generally, the highest measurement values were obtained for the wooden stamp with a rubber matrix (WR2) for all six measurements (see Figure 6). More specifically, for the wooden stamps, the rubber matrix (WR2) systematically presented higher mean results than the photopolymer matrix (WP2); however some overlapping of the values was observed. This difference was larger for measurements M1, M3 and to some extent M4 (i.e. these are vertical and diagonal measurements). On the contrary, larger overlapping of the distributions occurred for measurements M5 and M6, and to some extent M2. No tendencies were observed for the self-inking stamps (SP2 and SR2), one matrix showing sometimes higher, sometimes lower mean values depending on the measurements. Similarly no significant differences were measured between wooden and self-inking stamps. The largest difference between two impressions made from different stamps was measured for measurement M4 with a value of **0.12 cm** (WR2-SP2), only slightly higher than the maximal difference obtained between impressions made with a same stamp (0.09 cm).



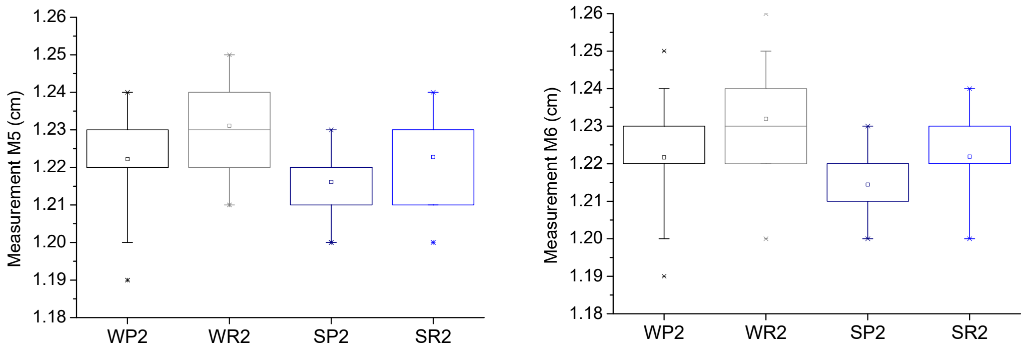


Figure 6 – Boxplots representing the data acquired on 36 stamp impressions for the wooden stamps and self-inking stamps made of photopolymer and rubber from manufacturer 2 (WP2, WR2, SP2 and SR2). The box represents the 25 / 75% percentile. While the median is represented by the central line, the mean is indicated by a small square. The crosses represent the minimal and maximal values, while the external lines represent the 1 / 99% percentile.

The results of the Wilcoxon test corroborated a significant difference only for the comparison of photopolymeric and rubber wooden stamps for all six measurements (see WP2 and WR2 distributions in Figure 6). While the difference was statistically significant, the mean differences observed when comparing rubber and photopolymer stamps remained relatively small (0.010 to 0.028 cm in Table 5). Moreover, all other comparisons yielded mixed significance depending on the measurements (i.e., for some measurements the means were statistically different, but not for others). Thus, while some differences were actually measured between impressions made using different stamps from manufacturer 2, these are generally lower than the maximal difference 0f 0.09 cm measured for the intra-variability measured. In practice, stamps impressions are often superposed to visualize a difference in size. If the two impressions showing the largest differences were superposed, the visible difference remained in fact quite small (Figure 7 - left).

Measurement	**Mean (cm)**			**Mean difference (cm)**	
	WP2	**WR2**	**WP1**	**WP2-WR2**	**WP1-WP2**
M1	3.844	3.867	3.648	0.023	0.196
M2	3.855	3.879	3.657	0.024	0.198
M3	3.369	3.397	3.181	0.028	0.188

M4	3.372	3.393	3.196	0.021	0.176
M5	1.222	1.231	1.163	0.009	0.059
M6	1.222	1.232	1.157	0.010	0.065

Table 5 - Difference between the mean values obtained for the photopolymer and rubber matrixes (wooden stamps from manufacturer 1 and 2). Values in red are above the mean maximal difference observed for impression made with the same stamp.

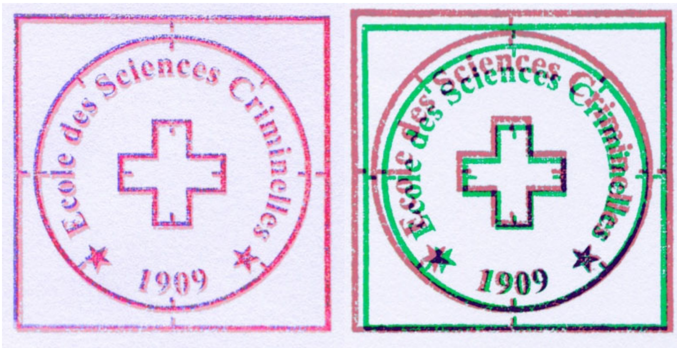


Figure 7 – *Left:* Stamp impressions superposition made from a rubber material (WR2 in blue) and a photopolymer material (WP2 in red). The measured difference reached up to 0.12 cm.
Right: Stamp impressions superposition made from the wooden photopolymer stamps from manufacturer 1 (WP1 in green) and manufacturer 2 (WP2 in red). The measured difference reached up to 0.29 cm.

The variability of impressions made with stamps from different manufacturers was very large up to **0.29 cm** (see example in Figure 8 and mean measurements in Table 5). This was the highest difference obtained for all experiments performed in this study and can mainly be explained by the fact that the two manufacturers interpreted the given size instructions differently. Manufacturer 1 calculated 4 x 4 cm for the polymer material, the stamp impression being slightly smaller. Manufacturer 2 produced a stamp impression measuring as required 4 x 4 cm. The Wilcoxon test confirmed that the two distributions were significantly different. The superposition of the two impressions of the different stamps also revealed the large difference in size (Figure 7 - right). Such a difference would support the hypothesis that the two impressions were made with different stamps rather than the same stamp.

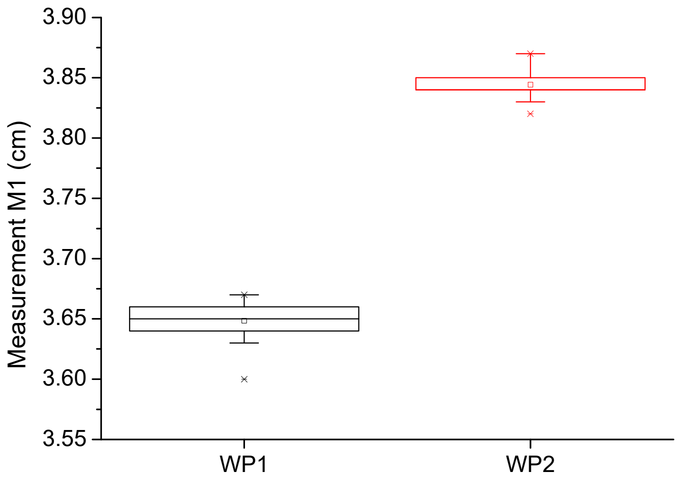


Figure 8 – Boxplots representing the data acquired for measurement 1 on 36 stamp impressions for the photopolymeric wooden stamps from manufacturers 1 and 2 (WP1 – WP2).

3.3. Influence of applied pressure

The effect of apposition pressure was evaluated using very low compared to very high pressure using the two wood stamps from manufacturer 2 (WP2 and WR2). No tendencies were highlighted concerning the applied pressure, indicating that this factor does not significantly influence the impression size (see example for the wooden rubber stamp in Figure 9). In fact, the overall absolute and relative errors for each measurement, as well as the maximal differences between values, remained in the limits of the reproducibility calculated above whatever the applied pressure for the two stamp matrixes (see Table 4).

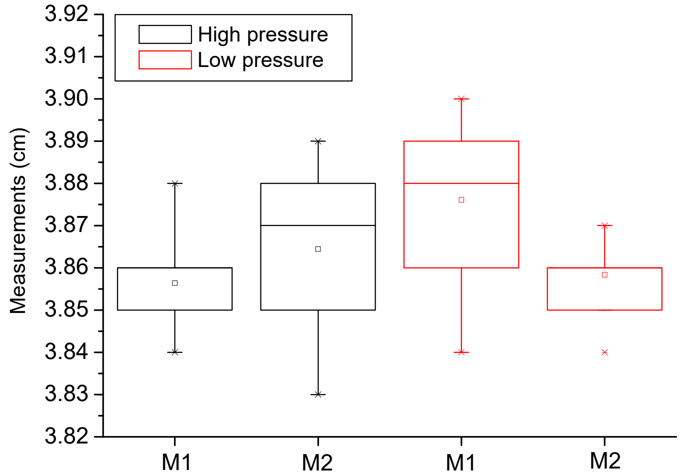


Figure 9 – Boxplots for the data acquired on high and low pressure for measurement 1 (M1) and 2 (M2) on impressions made with a wooden rubber stamp from manufacturer 2 (WR2).

3.4. Influence of humidity

In order to evaluate the influence of humidity, a relative humidity of 80% was selected to store the material (paper and wood stamps from manufacturer 2). The appositions of the stamps on paper were made in the same environmental conditions. Then, the paper with the stamp impressions was immediately scanned (while still humid) or dried in normal condition of ca. 30% relative humidity before being scanned. No influence of a high humidity on the size of the stamp prints was observed when the paper was scanned in the same humidity conditions. The mean size decreased slightly when the paper was dried before being scanned, however the differences were not statistically significant (see examples for measurement 1 and 2 in Figure 10 and Table 6). The maximal difference between two stamp impressions made in different relative humidity conditions was 0.09 cm. Thus, the tested humidity conditions did not influence significantly the stamp impression size.

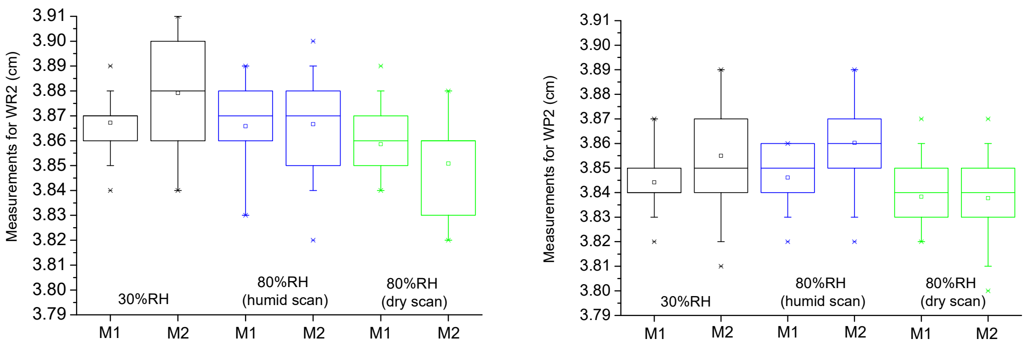


Figure 10 – Boxplots for the data acquired for measurement M1 and M2 on impressions made with photopolymer (left, WP2) and rubber (right, WR2) stamps in 80% relative humidity (RH) conditions compared to normal conditions (30% RH).

M2 (cm)	WP2		WR2	
	30% RH	80 %RH (dry scan)	30% RH	80 %RH (dry scan)
Mean	3.855 ± 0.023	3.838 ± 0.019	3.879 ± 0.022	3.851 ± 0.019
RSD	0.60%	0.49%	0.56%	0.49%
Min	3.81	**3.80**	3.84	**3.82**
Max	**3.89**	3.87	**3.91**	3.88
Mean difference (maximal difference)	**0.017 (0.09)**		**0.028 (0.09)**	

Table 6 – Mean values, absolute errors and relative standard deviation (RSD) for measurement M2 (cm) in low and high relative humidity (RH). Two wood stamps were used: photopolymer (P) and rubber (R). Minimal and maximal values are also indicated (min/max). A maximal difference of 0.09 was obtained.

3.4.1. Influence of temperature

The influence of low (5°C) and high (50°C) temperature was tested on the two wood stamps from manufacturer 2 in order to evaluate the effect of extreme climatic conditions on the stamp impressions. Similar results were obtained for both types of stamps and no effect of the temperature was detected (see Figure 11 and Table 7). In fact, the measured differences were equal or below the absolute errors calculated for impressions made in standard conditions (see Table 4, the maximal absolute error of 0.026 was obtained for measurement 2). The maximal difference obtained between two measurements made at 5 and 50°C was 0.08 cm. Thus, the tested temperature did not influence significantly the size of the stamp impressions.

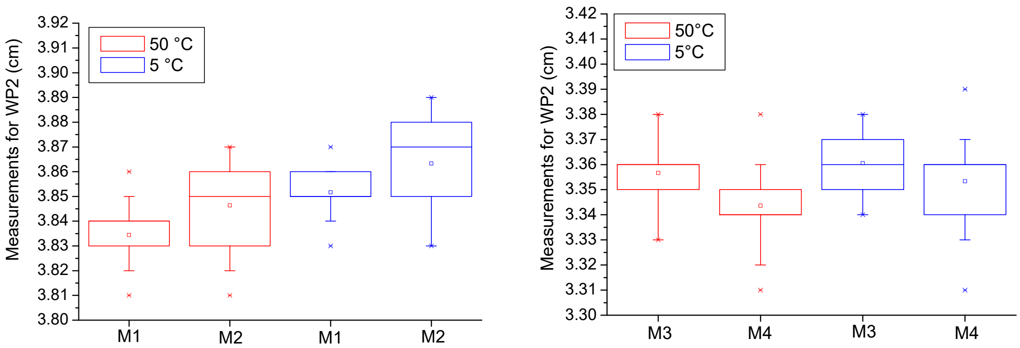


Figure 11 – Boxplots for the data acquired for measurements M1-M4 on impressions made with the wooden photopolymer stamp (2WP) at 5 and 50°C. While the mean values are slightly higher at 5°C, data overlap largely.

Measurement (cm)		WP2		WR2	
		50°C	5°C	50°C	5°C
Mean ± absolute errors	M1	3.834 ± 0.011	3.852 ± 0.008	3.854 ± 0.009	3.868 ± 0.011
	M2	3.846 ± 0.017	3.863 ± 0.019	3.865 ± 0.019	3.880 ± 0.019
	M3	3.357 ± 0.013	3.361±0.013	3.372 ± 0.011	3.378 ± 0.011
	M4	3.344 ± 0.014	3.353 ± 0.015	3.356 ± 0.014	3.368 ± 0.015
Mean difference (maximal difference)	M1	0.017 (0.06)		0.014 (0.05)	
	M2	0.017 (0.08)		0.015 (0.07)	
	M3	0.004 (0.05)		0.005 (0.05)	
	M4	0.010 (0.08)		0.013 (0.07)	

Table 7 – Mean values and absolute errors calculated for two wood stamps (above). The mean and maximal differences are also indicated (below).

3.5. Influence of time

Again, no significant difference was observed in the size of the stamp impressions one year after application. The ink did not migrate or diffuse over that period of time. The new stamp impressions using photopolymeric and rubber matrices did not show any difference in size. All measurements were well within the measured intra-variability.

4. Discussion and conclusion

The size differences measured between two stamp impressions are summarized in Table 8. When two impressions were made with the same stamp (intra-variability), a maximal difference of 0.09 cm was observed whatever the apposition or environmental conditions. Thus, neither the tested pressure, the humidity, temperature nor the age had an influence on the actual size of the apposed stamp impression.

The differences observed in this work were actually much smaller than those observed in a previous study (7). Pang et al. observed up to 2 mm differences in stamp impressions exposed to similar environmental conditions as those tested in the present work. However, it seems that the stamps they used, which were pre-inked stamps, were repeatedly exposed to the tested conditions over 25 to 36 days. Thus, the used matrixes did shrink over time. As it was not specified if those stamps were made of photopolymer or rubber material, differences in the material used might also explain this extreme differences. However, if the questioned and reference impressions were made relatively close in time and were stored at ambient conditions, no large differences should be expected due to intra-variability.

When two different stamps were used (different matrices and apposition techniques), then the maximal size difference reached 0.12 cm, but most measurements actually remained under the measured intra-variability. When stamps were produced by different manufacturers, the difference could reach up to 0.29 cm. In practice, based on the findings of this study, a difference above 0.09 cm supports the hypothesis that the stamp impressions were made using two different stamps rather than the same stamp. Mean absolute error reached up to 0.026 cm. Interestingly, the largest horizontal measurement (M2) generally yielded the largest absolute variation compared to its equivalent vertical measurement (M1). This was not confirmed for the lowest vertical and horizontal measurement M5 and M6.

Size difference observed between two stamp impressions	**Possible explanation for the difference**
$0.00 \leq x \leq 0.09$ cm	Intra-variability (same stamp)
$0.00 \leq x \leq 0.12$ cm	Inter-variability (same manufacturer)
$0.06 \leq x \leq 0.29$ cm	Inter-variability (different manufacturer)

Table 8 – Minimal and maximal size differences measured between two stamp impressions are summarized. Forensic meaning is also discussed.

In conclusion, this study demonstrated that no significant differences in stamp measurement were due to different apposition and storage conditions of the stamps and impressions. Differences larger than 0.09 supported the hypothesis that two different stamps were actually used. These results will help questioned document experts in their evaluation when confronted to the examination of questioned and reference stamps in practice.

5. Acknowledgments

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