DNB Working Paper
No. 680 / April 2020

Banknote verification relies on vision, feel and a single second

Frank van der Horst, Jelle Miedema, Joshua Snell and Jan Theeuwes

DeNederlandscheBank
EUROSYSTEEM

Banknote verification relies on vision, feel and a single second

Frank van der Horst, Jelle Miedema, Joshua Snell and Jan Theeuwes*

* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

Working Paper No. 680

April 2020

De Nederlandsche Bank NV
P.O. Box 98
1000 AB AMSTERDAM
The Netherlands

Banknote verification relies on vision, feel and a single second

Frank van der Horst[a], Jelle Miedema[b], Joshua Snell[c] and Jan Theeuwes[c]

[a] De Nederlandsche Bank, Amsterdam
[b] De Nederlandsche Bank, Amsterdam (current address Thales, Hengelo)
[c] Vrije Universiteit, Amsterdam

April 2020

Abstract

Central banks incorporate various security features in their banknotes to enable the general public, retailers, professional cash handlers and central banks to detect counterfeits. In this study we conducted two field experiments to test the extent to which euro banknotes can be authenticated as a function of exposure time and perceptual modality. In addition we investigated if these effects are moderated by expertise. In both experiments, the counterfeit banknotes were actual counterfeits taken out of circulation.

Experiment 1 showed that the public (i.e., non-experts) is only to a limited extent able to visually distinguish between genuine and counterfeit banknotes. Importantly, while being impacted by expertise, overall performance was not significantly affected by exposure time.

Experiment 2 gauged haptic perception in addition to vision, taking into account the fact that in regular cash transactions, people might see only one side of the banknote, but will always feel both sides. Experiment 2 showed that a combination of sight and touch produced much better performance than touch alone. Unlike Experiment 1, exposure duration resulted in better performance in Experiment 2.

The data of Experiment 1 and 2 indicate that banknote authentication is best when one can employ multiple sensory modalities. Moreover, as such, non-experts exhibit a very decent performance even with a one second exposure duration. Experts do an even better job. When being allowed to use only one perceptual modality, performance was equal for respectively haptic and visual perception when exposure time was long. In the short time condition it was more helpful to see than to feel.

Our results are also inconsistent with the often expressed notion that people can instantly feel whether a banknote is fake or genuine. On the contrary, we found that exposure duration is important when participants could hold a banknote in their hands, with performance improving upon a longer exposure duration. The best performance in banknote authentication is realized by a combination of vision, feel and a few seconds.

The study proposes a dual processing model for banknote authentication. As long as people have trust in the cash system, the situation in which the transaction takes place and the banknote itself, they authenticate quickly, effortless and automatically (Type 1 processing). If not, this mode will be overridden by Type 2 processing, and people will explicitly and deliberately authenticate banknotes. In this study, as they were asked to authenticate, the participants processed according to Type 2. Even though in everyday life people hardly ever deliberately check whether a banknote is counterfeit or not, the findings indicate that they are quite capable of doing this. The current findings suggest that when developing new series central banks should continue to address both senses. The good results for combined look and feel also suggest that in the development and evaluation of security features, future investigations should mimic real-life interactions rather than mere visual presentation on a computer screen. Lastly, the results of the study are consistent with the statement of the Eurosystem that it only takes a few seconds to authenticate a banknote.

Keywords: attention, decision-making, change blindness, gist, sight, touch, authentication, banknotes, counterfeits.
JEL codes: E40, E41, E50, E58.

Introduction

In 2016, consumers in the euro area made on average 1.2 cash payments per day (Esselink & Hernandez, 2017). These cash transactions were largely habitual (Van der Horst & Matthijsen, 2013). Upon receiving a banknote – either from a retailer or in a person-to-person transaction – people typically prioritize determining its value. Determining whether the banknote is fake or real is regarded as less important (Klöne, Vrakking & Zondervan, 2019). Citizens of the Euro area tend to have strong confidence in the authenticity of banknotes because the likelihood of receiving a counterfeit is very low (Van der Horst, De Heij, Miedema & Van der Woude, 2017b). For example, in 2018, the number of counterfeit euro banknotes removed from circulation (563,000) constituted only 0.003% of the number of genuine euro banknotes in circulation (22 billion) (ECB, 2019). Mainly because of this, people tend to not authenticate banknotes especially when, at first glance, the banknote appears normal (Van der Horst et al., 2017b). Indeed, in the study of Klöne et al. (2019), 70% of a sample of Dutch respondents claimed to have never intentionally and consciously authenticated a banknote in the last five years.

The relatively high levels of trust exhibited by citizens of the Euro area fuel the need for banknotes of which the authenticity can be easily confirmed—which, in consequence, should boost one's ability to detect deviants beyond the limits imposed by naïveté. For these reasons, all central banks incorporate various security features in their banknotes to assist user groups in identifying counterfeits without specialized equipment. Examples are a watermark, a security thread that is imbedded in the paper, optically changing elements, security foils (sometimes including holograms), paper structure and the relief caused by intaglio printing (raised ink). These authentication features appeal to two of our five senses, namely sight and touch (see Figure 1).

As of yet, we do not have complete knowledge of the factors contributing to counterfeit detectability. In particular, we know little of the respective contribution of visual and haptic perception in the decision process. We additionally do not know how much time is warranted to ensure that the exploitation of these senses prompts at least a decent detection performance (e.g., would one either feel anomalies within a split second or never at all, or would anomaly detection improve as one accrues more haptic evidence over time?). Lastly, we do not yet know how these factors are influenced by expertise (e.g., might expertise increase the value of evidence accrued beyond the first impression?). The present study is aimed at answering these questions.

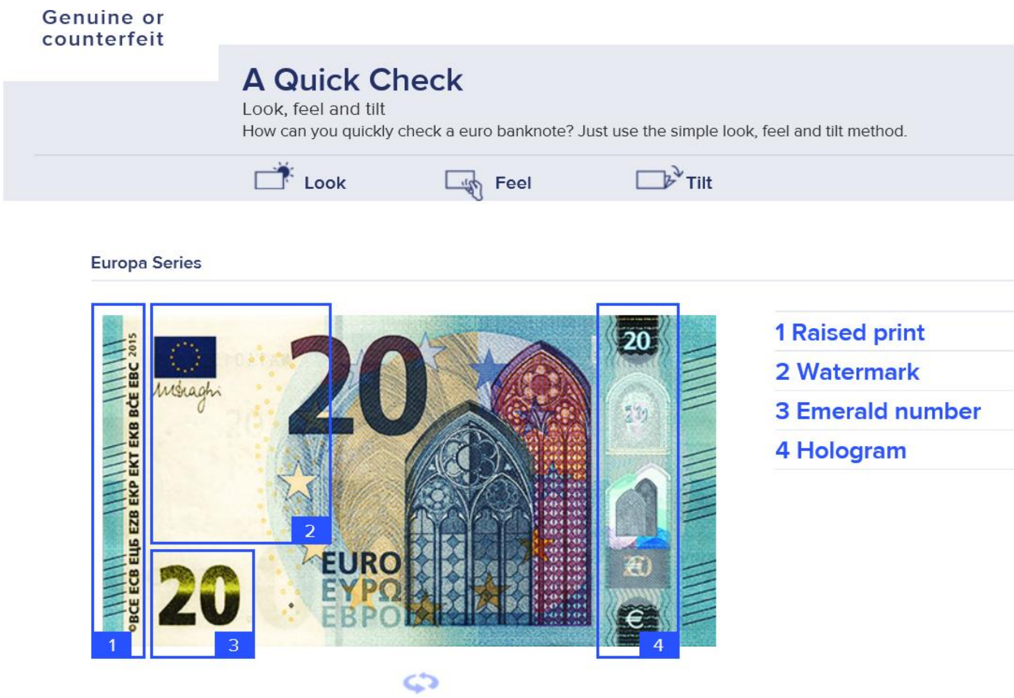


Figure 1. Security features for the public shown on the website of DNB[1].

Two decision systems

Before reporting our experiments, we should outline a few theoretical constraints. Prior research has led to believe that humans have two separate cognitive systems driving decision-making. One of these is fast, automatic and largely non-conscious; a type of processing that has been labelled System or Type 1 processing (Frankish, 2010; Kahneman, 2010). In the present context it could be argued that a typical cash transaction would involve naught but Type 1 processing. However, in probing counterfeit detection with a cognitive experiment, we may inherently be unable to assess Type 1 processing: specifically, asking participants whether a given banknote is real or fake is likely to induce atypical levels of distrust. In consequence, authentication would consist of a more slow, controlled and conscious decision process, which in the literature has been labelled System or Type 2 processing (Frankish, 2010; Kahneman, 2010). Hence, in assessing the interactions of perceptual modality, time and expertise in the detection of counterfeit banknotes, our conclusions shall largely pertain to Type 2 decision making processes, illustrated in Figure 2. The extent to which findings may inform us about Type 1 processes will be reflected upon in the Discussion.

[1] www.dnb.nl/echtofvals.

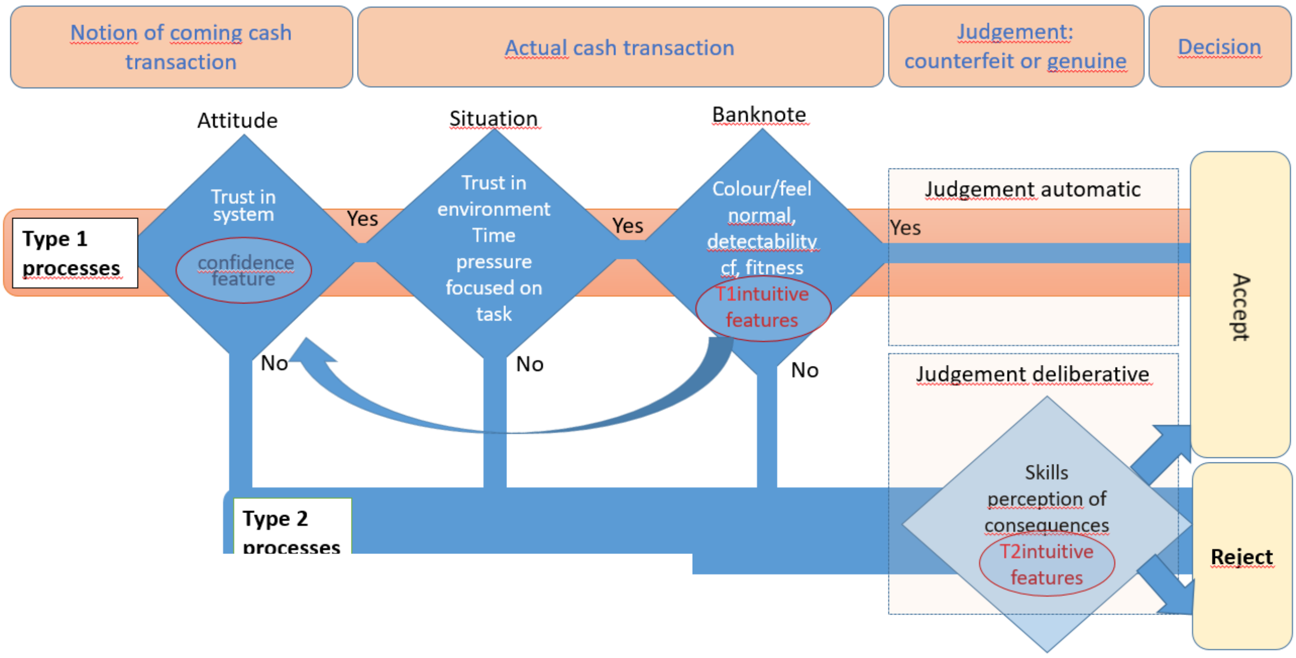


Figure 2. Dual processing model when receiving a banknote

The model of Figure 2 comprises four phases. The first phase starts when a person is aware that he will receive a banknote, for instance as change from a retailer. The next phase consists of receiving the cash, after which in phase three he implicitly or explicitly makes some assessment regarding the genuineness of the banknote. The fourth and last phase is that the receiver decides to accept or reject the banknote. The cognitive processing in these four phases is described below:

Even before the banknote has been received, people will have a particular attitude towards cash transactions in general. The moment that people know a cash transaction will take place, whether they engage in the default mode (Type 1) or whether this mode will be overridden by the more deliberative process (Type 2) will depend on the trust they have in the functioning of the cash system. Dutch respondents indicated to check more regularly when the media report on existing prevalence of counterfeits or when they have been the victim of counterfeiting (Klöne et al., 2019). Also, as said, participants in this cognitive experiment will assess deliberately. The integration of confidence security features may add to the trust in the authenticity of the banknote; these features should give the sense that the banknote is hard to counterfeit (Van der Horst et al., 2017b). Note that in reality, the addition of these features may not help much in the ability to detect counterfeits but may nevertheless increase the trust in the banknote and the system as a whole.

The next phase is when the cash transaction actually takes place. If there is nothing unusual in the environment, like in the local supermarket, or when people are distracted and the perceptual workload is high, people will engage in Type 1 processing. On the other hand, if the environment is not trustworthy, people are likely to be more cautious and Type 1 may be overridden by Type 2 processing.

The banknote itself might also be a trigger to pay more attention. For example, when the colour or print quality is unusual, badly mimicked or the paper feels different, or when it is a very dirty banknote, people are triggered to check the banknote more deliberately (Klöne et al., 2019). If a genuine banknote contains features that 'pop out' of the surroundings, it is likely that these features draw attention automatically. Such features could be described as Type 1 intuitive security features. When such a Type 1 intuitive feature is missing, or badly mimicked, the receiver will have a feeling that "there is something wrong" and this may trigger a more thorough examination of the banknote. The term contains the word 'intuitive' as no prior knowledge on how to check the security feature exactly is necessarily triggered when the mimicked Type 1 intuitive security feature obviously differs from a genuine banknote.

The third phase is when the judgement takes place. If the Type 1 processing has not been overridden at this point, the banknote will be automatically, and implicitly, judged as genuine and accepted in phase four. However, if the person processes according to Type 2, the decision to accept or reject depends on his authentication skills, prior knowledge of security features and the perception of the consequences. An example of the latter is that according to a survey 19% of the Dutch retailers choose to accept a counterfeit, even though they know it is fake (Hoevenagel, Van Marwijk, Wils & Bolle, 2015). Processing can be helpful when the banknote contains intuitive security features, meaning that they can be understood instinctively, without the need for conscious reasoning. Type 2 intuitive security features will greatly assist non-experts.

Although the above framework describes the prerequisites for engaging in higher-quality Type 2 processing, it must be stressed that human authentication has its limits even when invoking Type 2. Change blindness experiments show that people do not automatically form a complete and detailed visual representation of scenes in memory (Sampanes et al., 2008). The term change blindness refers to the surprising difficulty observers have in noticing large changes to visual scenes (Simons & Rensink, 2005). Similarly, people will not have a complete representation in memory of all the different euro banknotes. In order to detect a change, attention should be first drawn to the features that have changed (Simons & Levin, 1998). But attention alone is not necessarily sufficient. Even if this is the case, the changes can go unnoticed, in particular when they are unexpected (Healey & Enns, 2012). In some situations, people are surprisingly slow or entirely unable to detect changes made to, or find differences between, two scenes (Nightingale et al., 2017; Standing et al., 1970). Similar findings have been reported in studies using altered images which to some extent is comparable to identifying counterfeit banknotes. In an experiment in which genuine and manipulated photographs were presented on a computer screen, it was shown that people have a poor ability to identify whether an image is the original or has been manipulated (Nightingale et al., 2017). Also, according to Standing et al. (1970) participants are unable to detect when a photograph has been mirror-reversed since this does not impact the gist.

In addition to attention, we must highlight the 'prevalence-effect'. Visual search experiments are perceptual tasks requiring active scanning of the visual environment for a particular object or feature (the target) among other objects or features (the distractors). In most visual search experiments, targets appear on at least 50% of trials (Wolfe & Van Wert, 2010). Wolfe & Van Wert showed in 2010 that when targets were rare (1% prevalence) observers made more than four times the errors made when targets were common (50% prevalence). To miss a disproportionate number of targets when these targets are rare, is especially problematic in important everyday contexts such as medical- or airport screening (Wolfe & Van Wert, 2010). Wolfe et al. (2005) showed that if observers repeatedly do not find their target, they will more probably fail to notice it once it does appear. Undoubtedly this prevalence effect is to impact on counterfeit detection as well, given that counterfeits in everyday life are extremely rare (Rich et al., 2008).

About time

Cash transactions are performed rapidly. What is considered a cash transition is mostly measured as the time from the moment the customer hears (or sees) the price of a product until the customer receives change and the receipt. The median transaction time for instance in Canada was estimated to be 11.6s (Kosse et al., 2017), 19s in the Netherlands (Brits and Winder, 2005) and 22.3s in Germany (Cabinakova et al., 2019). Sometimes transactions are conducted even faster. Layne-Farrar (2011) cites "industry reports" that indicate that cash transactions take 8-10s to complete. One element of the transaction can be the acceptance of one or more banknotes as change. At this point during the transaction people may engage in banknote authentication. However, it is not known how long exactly this part of the transaction takes. An internal DNB cashier field study (Zondervan & Heinen, 2019) shows that most cashiers made - implicit or explicit and without the use of authenticating devices - the decision whether or not to accept a banknote within three seconds. According to Layne-Farrar (2011) it takes only 1-2s for waiters to pick up money from a table for a tip and pocket it. The simple task of accepting a banknote and storing it in your wallet is probably within that range of time. Allegedly, this is also the time that the banknote has been authenticated, at least implicitly. Some national central banks of the Eurosystem (e.g. Bank of Italy (2020) and Bank of Finland (2020)) state on their websites that it only takes a few seconds to (explicitly) authenticate a banknote. However, as far as is known there has been no empirical evidence regarding the speed with which banknote can be recognized as counterfeit or genuine. In the current study, the task was to decide whether a banknote was counterfeit or genuine and the exposure duration to the banknote was systematically varied.

As suggested before, it is unknown whether counterfeit detection would benefit from a longer exposure duration. However, research on scene perception may be somewhat informative, as it has revealed that people are able to recognize complex real-world scenes at a mere glance, regardless of the visual complexity of the scene (for instance Oliva, 2005, Fei fei et al., 2007)). Importantly, this type of recognition concerned the gist of the scene (e.g., ‘it is an outdoor scene with mountains’) without concern for specific features or details. Possibly, perceiving details is a prerequisite for successful counterfeit detection.

The Feature Integration Theory (Treisman & Gelade, 1980) may provide some additional ideas about how quickly people are able to recognize specific features of a banknote. According to this theory, there are two stages in visual search: a pre-attentive stage (“vision” before attention) in which a limited number of basic features can be processed simultaneously (in parallel) and an attentive stage in which more complex items are inspected in a serial effortful way. Treisman and Gelade proposed that only a limited set of specific features can be detected pre-attentively. Targets defined by unique features are assumed to pop out from the background. According to Wolfe and Horowitz (2017) there are probably two dozen attributes that guide bottom-up attention, some of which are under discussion. However, undoubted guiding attributes are: color, motion, orientation and size. Pre-attentive searching for a target is very efficient. During pre-attentive searching, the time for detecting whether or not a target is present (Reaction Time, or RT) is independent of the number of items in the display (set size) (Wolfe, 2003). A red target amongst green distractors stands out and commands attention with minimal interference from the distractors. Even though nowadays there is some discussion on whether searching is ever truly pre-attentive (i.e., “before attention”), the underlying concept that specific features can be detected very efficiently with much effort is very useful. Specifically, this mode of processing can help rapidly draw the focus of attention to specific features without much interference from other features. It is generally believed that presenting a display for only 200 ms should be enough for detecting these basic features. Because the time it takes to make a saccadic movement is at least 200 ms, such a task is completed in a single glance (Healey & Enns, 2012). The recognition and discrimination of patterns appears to take longer. According to Fei-Fei et al. (2007) observers need 500 ms to categorize outdoor and indoor scenes. In their study it was shown that when presenting cluttered and complex scenes, extending the presentation time for an image from 107 ms to 500 ms improved the perception of details. Furthermore, a study by Greene et al. (2015) showed that participants can make an adequate description of typical real-world situations scenes in 506 ms., although it takes participants longer to understand and even perceive improbable visual images, like a press conference under water, indicating that our rapid scene categorization abilities depend critically on our prior experience with real-world environments (Greene et al. 2015).

As noted earlier, one of the goals of this study was to determine the lower limit on how rapidly people can distinguish counterfeit from real banknotes. If counterfeits are distinct from genuine banknotes by virtue of features that stand out then one should be able to do this very rapidly. In the set of exposure times employed in our experiments, we therefore incorporated a 500 ms condition, which represents a time in which one or two eye movements can be made. We also tested longer exposure durations of 1,000 ms and 10,000 ms to determine whether a longer exposure duration would improve performance. Indeed, if the detection of counterfeit banknotes requires the processing of specific details, we would expect that a longer exposure duration would greatly improve performance. As an upper limit we used an exposure duration of 10,000 ms, as it was previously shown that the hit rate in detecting a counterfeit does not increase beyond an exposure duration of ten seconds (Van der Horst et al., 2016).

As argued before, it remains to be seen to what extent these temporal constraints are modulated by certain factors, such as expertise and perceptual modality. Whereas the above findings pertain to vision, haptic perception is likely to play a considerable role in counterfeit detectability as well. Below, we provide a brief review of the tenets of touch with respect to counterfeit detectability.

Touching on touch

When both visual and haptic perception are available, it is likely they will play an interactive role (Wijntjes et al., 2009, cited by De Heij, 2017; Kandula, Hofman, Dijkerman, 2015). An example of such an interaction is the rubber hand illusion: watching a rubber hand being stroked, while one's own unseen hand is synchronously stroked, may cause the rubber hand to be attributed to one's own body, to "feel like it's my hand." (Tsakiris, Manos, Haggard & Patrick, 2005). Touching paper, like turning the page of a book, opening mail or handling a banknote, is an action that everyone executes daily. When using a banknote, people might see only one side of it, but will always feel both sides.

The haptic stimulation by banknotes was studied by Wijntjes (2009). This study indicated that a cash handler that receives a banknote will examine it haptically before placing it in the cash register. Usually a banknote is held between two fingers, the index finger on the reverse and the thumb on the front. The (side of the) middle finger may assist the index finger, exerting counter-pressure to the thumb. Some specific interactions are illustrated in Figure 3. The picture on the left shows the bending of the paper, the picture in the middle shows planar movement of the thumb and the picture on the right shows the multiple contact areas. The cash handler thus perceives various banknote properties such as feel of the paper and raised ink with their fingertips.

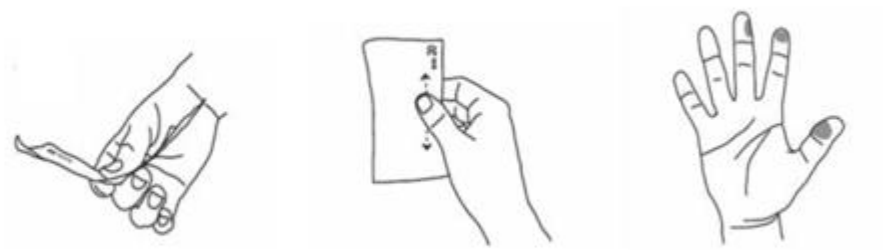


Figure 3. Haptic banknote interaction. Left: movement over the surface. Bending of the paper, fingers on two sides. Thumb on the front and index finger on reverse. The middle finger is sideways supporting the index finger. Middle: multiple contact areas. Thumb (and not index finger) is used to rub to and fro. It is assumed that typical movement ranges are about 20 mm. Right: Various banknote properties are perceived with three fingertips (thumb, index and middle finger). Illustrations by Wijntjes (2009).

Zondervan & Heinen (2019) carried out an in-house study for De Nederlandsche Bank in which two 'mystery shoppers' purchased a product at 30 shops and paid with an artificially-modified genuine banknote. The cashier's behavior was assessed when they were confronted with these ‘suspicious’ banknotes. One of the findings was that approximately half of the retailers authenticate banknotes with the tips of their fingers.

Prior haptic perception research has shown that humans are very good at recognizing common objects like paper within only a few seconds on the basis of touch alone (Lederman et al., 1993). Tactile information is processed even if people do not deliberately intend to do so. According to De Heij (2017) several studies have shown that people are triggered to perform an authenticity check on a banknote they just received when ‘it felt different’. In line with this, the ECB recognizes that the feel and touch of a banknote is an important feature for detecting counterfeits. The feel includes the paper itself (‘feel the banknote, it is crispy and firm’) and the raised print (‘feel the short raised lines on the left and the right edges of the banknote. The main image and the large value numeral also feel thicker’) (ECB leaflet, 2013). The ink layer of the banknote is in general up to about 60 µm high. However, this height decreases when banknotes are used intensively. According to De Heij (2017) deterioration of banknotes is caused by relaxation of the paper fibers, and also by all sorts of wear and tear. Wrinkles in a banknote will create a ‘tactile noise level’. A study by Raymond (2017) was designed to allow for perception testing and discrimination based on ‘intaglio only’ (raised print). Different from the present study, the banknotes were specifically manufactured for this study. Respondents had to learn about the fantasy notes and the counterfeits were made artificially (that is, they were not removed from circulation as in the current study). Raymond et al., used three soil levels and three variants of counterfeits, similar to what is seen for actual counterfeits. The results showed that sensitivity to detect counterfeits was adequate across all soil levels, even when very high-quality counterfeits were presented. Raymond concluded that tactile information appears to afford better counterfeit detection than just visual information, regardless of soil level. Tactile information seems to also play a key role in authenticity judgements. It was concluded that intaglio (raised print) provides a distinctive look and feel to notes that is not easily mimicked by using other printing techniques. People who used their fingers in an explorative way when inspecting the new note at the beginning of the study (‘tactile explorers’) are better at counterfeit detection in general.

Next to intaglio (raised ink), the substrate or matter of the banknote, the paper itself, is useful for authentication purposes. A 2013 cash survey by the Bank of Spain (Pérez et al., 2014) indicated that this was the most frequently verified security feature by both the general public and retailers. A study by Summers et al. (2008) was conducted on the discrimination of ten different types of plain paper on the basis of only a few seconds contact. Summers concluded that two perceptual dimensions, namely roughness and stiffness, are used to discriminate the paper. However, as with raised ink, a drawback of these factors is that they change dramatically over the banknote's lifetime.

To quantify the potential of tactile discrimination in counterfeit detection, in one of our current experiments we included a condition in which participants could only feel the banknote. Comparing this condition with a "see only" condition allowed us to quantify how important tactile information really is. Finally, the experiment also comprised a condition combining vision and touch, which is more equivalent to real-life transactions. As far as we know, multi-sensory authentication of banknotes has only been previously investigated by Klein et al. (2004). In subtests of this study, the objective was to compare inspection of banknotes using sight alone, touch alone and sight and touch combined. In the sight condition, the notes were put in plastic sleeves so the participants could not feel them. In the touch condition the participants were allowed to touch the notes, but sight of the notes was blocked by a screen. Participants performed better when they saw the notes while unable to touch them (87%) than vice versa (74%). When sight and touch were combined the detection rate was on average 92%.

As acknowledged before, in the current study participants were asked to determine whether a banknote is counterfeit or not, which is quite unlike cash transactions in real life, in the sense that it appeals more to Type 2 processes than Type 1 processes. We take note here of one study that has tried to circumvent this limitation. In a study conducted by Bank of Canada (Omrane, B. et al., 2018), participants were instructed to focus on a cash-handling task and were not informed that the deck consisted of genuine and counterfeit banknotes. The participant's primary task was to place banknotes in a specific orientation ('face-up') as quickly as possible. As a secondary task, participants were also asked to remove 'odd-looking' banknotes. This approach was chosen as it was assumed that in real life people focus more on cash handling than on authentication. It was found that this instruction led to occasional detection of counterfeits. Note however that counterfeit detection performance in this study was much lower than when participants had counterfeit detection as their main task (Omrane, B. et al., 2018).

In sum, we wanted to know how well experts and non-experts are able to authenticate banknotes using different senses and how this authentication is affected by exposure time. We studied this in two separate experiments. In Experiment 1, the task for participants was to distinguish images of genuine banknotes from counterfeits by visual inspection on a computer display. In Experiment 2, participants had to tell apart physical genuine banknotes and counterfeits by only touching them or by touching and seeing them.

Method Experiment 1: ‘looking’ (screen test)

Participants

Participants from the general public were recruited between November 2018 and February 2019 by approaching persons at locations like community centers, schools, fairs, clubs, etc. It was explained that both test leaders work at DNB and that research was conducted to investigate how well people can detect counterfeits as this is important information for central banks. The tests were done on a voluntary basis. Every time before the test started the same introduction was read out loud by the test leader (Annex). All received a USB-stick in the form of a gold bar as a small gift (unannounced and only after the test). Most people declared after the test that it was interesting and that they liked doing it. Sixty-three participants from the general public performed the screen test for all three conditions (maximum of 500 ms, 1,000 ms and 10,000 ms). The number of male and female participants was approximately equal and the age categories were well balanced. As such, in this respect, one can argue that our sample was adequately representing the Dutch population consistent with CBS demographic statistics (CBS Statline, 2020).

Experts were defined as people working at a national central bank, having counterfeits as an area of expertise in their work. This means that they could be for instance employees that analyse intercepted counterfeits on a daily basis at the national analysis center at DNB or at another national central bank from the Eurosystem. In these analysis centers counterfeits that are removed from circulation are registered and stored. Experts could also be employees advising on policy to combat counterfeiting. 14 Experts participated in Experiment 1.

Stimuli

To create a test set for the present experiment we made use of counterfeits that were stored at the national analysis center of De Nederlandsche Bank. The 20 counterfeits in the test set were selected on the basis of the following criteria:

- The counterfeits were used at least once in real life (at least one person has been tricked in real life by this counterfeit). This means that they had to be taken out of circulation.
- The denominations were the same as the denominations that are counterfeited the most often (EUR 20 and EUR 50). (ECB, 2019).
- The two banknote series (ES1 and ES2) that were in circulation at the time of the tests were equally represented.

- The counterfeits varied in mimicking quality. Most counterfeits were simply made with a copier, sometimes with an imitated foil attached (see for an example Figure 4). One of the samples was a so called ‘composed note’, i.e. partly genuine and partly counterfeit, which is considered to be a counterfeit in the Eurosystem.
- The counterfeits varied in fitness quality. The counterfeited banknotes should not feel, or look more worn than the genuine banknotes.

Next, the test set consisted of 40 used, genuine banknotes, which were still fit for usage. The genuine banknotes were the same denominations and of the same series as the counterfeits. The proportion between genuine and counterfeit was thus 2:1. This is a much higher probability of encountering a counterfeit than in real life, which is as noted earlier roughly 0.003%. Nonetheless, this was necessary to obtain sufficient measurements per condition. Participants did not know exactly how many counterfeits to expect, but they were told that “most banknotes are real, but a considerable number are fake”. The reason for this phrasing was to ensure participants could not calculate when they ‘were done’ and then stop reporting counterfeits, as well as to let participants know that genuine banknotes are in the majority, so they would not be too easily triggered to declare a banknote as counterfeit. See Table 1 for an overview of the contents of the test set.

In the screen test, images of the 60 banknotes were displayed in JPG-format, 2448 x 1956, resolution 300 dpi. The images were made with a Video Spectral Comparator 8000. The images were made in direct white light conditions, so that the reverse of the note was not visible through the front, as is the case with transparent lightning. The disadvantage of this method is that ‘look through’ elements, like the watermark and thread, are hardly visible. On the other hand, in everyday life these elements can only be seen when holding the banknote in front of a light source, which normally does not happen in cash transactions.

Figure 4. One of the counterfeits in the test set. The different foil is particularly visible. The counterfeit mimics a EUR 20 banknote from the second series.

Table 1. Contents stimuli in test set

		Counterfeit	**Genuine**	**Total**
EUR 20	First series (ES1)	5	10	15
	Second series (ES2)	5	10	15
EUR 50	First series (ES1)	5	10	15
	Second series (ES2)	5	10	15
Total		**20**	**40**	**60**

Procedure

The screen on which the banknotes were presented was a MultiSync PA242W. The "auto brightness" function was enabled so that the brightness level of the screen changed automatically according to the lighting conditions of the room. The pictures were enlarged 1.5 times to better mimic real life, as 40 centimeters is approximately the distance from the eye to a banknote in hand and 60 cm was approximately the distance from the eye to the monitor.

Figure 5. shows the trial procedure. Every trial started with a fixation dot in the center of the screen for 500 ms followed by a picture of the front side of a banknote (with

the pictures of windows and gateways). There were three exposure durations of either 500 ms, 1,000 ms or 10,000 ms (or until response) tested in separate blocks. For each participant the order of presentation of the blocks was random. Within each block, all 60 banknotes were presented in random order. Hence, each banknote was shown three times to each participant. Following the display presentation, participants were required to press the key ‘z’ on the keyboard if they thought the banknote was genuine or ‘/’ if they thought it was a counterfeit. They could press the key the moment they wanted to answer, so they did not have to wait until stimulus offset. For the sake of convenience, the keys were marked with green sticker for the ‘z’-key and a red one for the ‘/’-key. Participants received six practice trials. The experiment was run on OpenSesame software (Mathôt et al., 2012). The total test time took on average 25 minutes. After the test the participants were invited to fill in a short questionnaire, including questions on demographics, authenticating technique and professional cash experience.

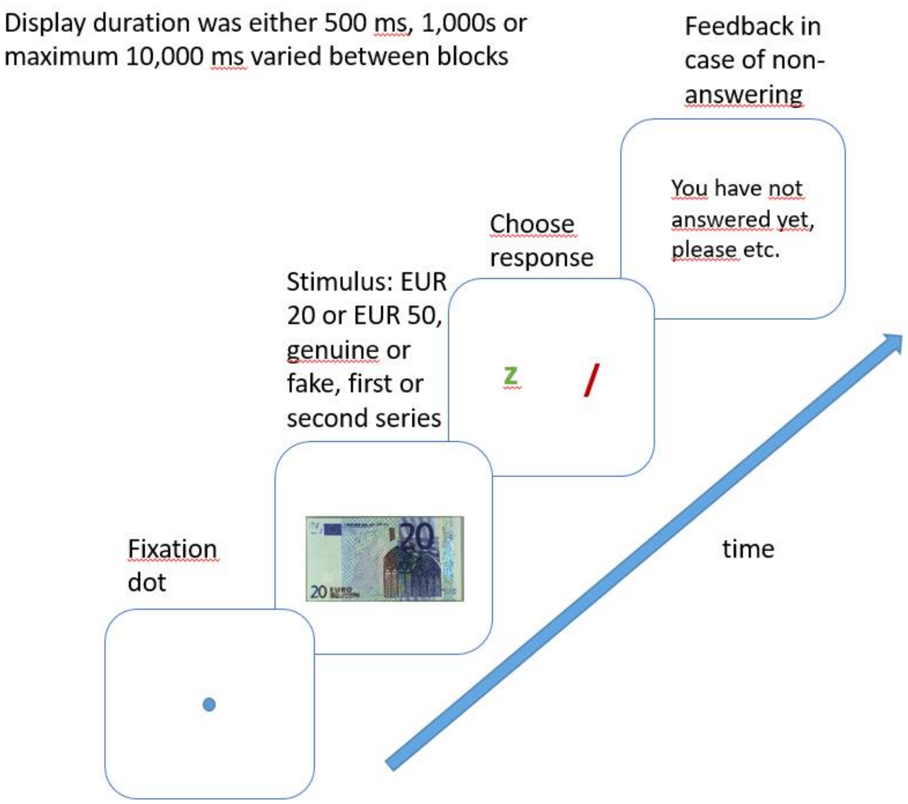


Figure 5. Procedure screen test. The core structure of the trial. Every trial started with a fixation dot in the center, for 500 ms, followed by a banknote (either EUR 20 or EUR 50, either genuine or counterfeit, either first or second series). The display duration was either 500 ms, 1,000 ms or maximum 10,000 ms varied between blocks. In case of not pressing the right key a reminder will be shown.

Method experiment 2: ‘feel’ and ‘look and feel’ (physical test)

Participants

The method of assessing public and experts was the same as it was in Experiment 1. In total 30 participants performed the test with physical banknotes. Half of the participants in this group (n=15) was randomly assigned to the long and short conditions of only feeling the banknotes while the other half (n=15) was assigned to the long and short conditions of both look and feel the banknotes. 10 Experts participated in Experiment 2. In both conditions these experts, just like the public, had to authenticate the banknotes in two time conditions, short exposure (around 1,000 ms) and long exposure (max. 10,000 ms).

Stimuli and procedure

The physical banknotes that were used to create images for this screen test, were also used in Experiment 2. In this second experiment participants were asked to authenticate the notes one by one as they were handed over to them, but half of the participants were blindfolded so that they could only feel the banknotes. The physical test was to find out how participants would perform if 1) they could only feel the banknotes, and 2) how they perform if they can both see and feel the banknotes. It was intended to compare the results of this second experiment with the results of the first experiment. In the physical test, all banknotes are handled by each participant. This handling causes deterioration in banknote quality, which means that the test set was not exactly the same across the whole experiment.

Table 2. Four conditions Experiment 2

	Feel	**Look and feel**
Short	1. Taking the banknote and touching it for about 1,000 ms	3. Taking, seeing and touching the banknotes for about 1,000 ms
Long	2. Taking the banknote and touching it for a maximum of 10,000 ms	4. Taking, seeing and touching the banknote for a maximum of 10,000 ms

Banknotes from a stack were handed over to the participants one by one by the test leaders with the front side up. The test leader did not look at the banknote in order to avoid giving clues as to whether banknotes were genuine. The banknotes could only be seen by the participants the moment they were handed over, as the rest of the stack was kept under the table. There were four conditions (see Table 2).

Each participant was randomly assigned to either the solely feel condition or the see and feel condition. Once assigned, each participant had to judge the 60 banknotes with a short handling time, or with a long handling time. The order of these blocks was random just as the banknotes were presented in random order.

Participants had to wear a sleep mask blocking their vision when they were tested in the feel only conditions. In the condition 'short' the test leader placed a banknote in a hand that was held open by the participant. The participant was asked to grab it with the other hand and in one movement place it either in front of them (condition feel) or in a box in order to prevent participants from seeing the banknotes after they had made their judgement (condition feel and seeing). The use of both hands is intended to make sure that there was no difference in perceptual capacity between left- and right-handed participants. Furthermore, the speed of the handling was designed to come as close as possible to the short presentation times used in the screen test. In a pilot, it was estimated that this handling would last approximately 1 s. The handling of the banknotes was recorded on video (note that only the participants' hands were filmed). It was made clear to the participants that faces would not be filmed or recognized. The filming was done in order to analyse off-line the exact duration of the authentication action (from receiving the banknote until putting it down). The analysis was done with Windows Movie Maker on Windows 10.

Results

Signal Detection Theory

In order to determine how well participants were able to detect counterfeits we used a measure derived from Signal Detection Theory (SDT). Participants may respond to a stimulus with a simple yes or no (“yes, the banknote was fake” or “no, the banknote was not fake”). ”). This gives the following responses. Fake banknotes could be correctly classified as counterfeit (‘hit’), a fake banknote could be incorrectly classified as genuine (‘miss’) , a genuine banknote could be classified as counterfeit (‘False Alarm’) and a genuine banknote could be correctly classified as genuine (‘correct rejection’).

Counterfeits are not reimbursed by central banks. So to avoid money loss it is key for people to recognize a counterfeit before accepting. So a high hit rate (in the test the number of hits divided by 20 counterfeits in the test set) is crucial. However, a low false alarm rate (the number of false alarms divided by 40 genuine banknotes in the test set), is also important for a good functioning of cash as a payment method. The ability to discriminate genuine banknotes from counterfeits is called sensitivity, combining hit and false alarm rates. One of the most commonly used statistics for computing sensitivity is d’, which can be estimated by deducting the z-transformed probability of false alarms from the z-transformed probability of hits.

$$d' = Z(\text{hit rate}) - Z(\text{false alarm rate}).$$

A d’-score of 0 signals an inability to distinguish counterfeits from genuine banknotes. According to Raymond (2017) a d’ of 1.25 represents a reasonably good performance in sensitivity in banknote authentication. The maximum d’-score that can be obtained in this study is 3.92.

Furthermore, people may have different decision strategies. The response bias is the extent to which one response is more probable than another. That is, a receiver may be more likely to respond that a stimulus is present (the banknote is a counterfeit) or more likely to respond that a stimulus is not present (the banknote is genuine). A commonly used statistic for this response bias is β. A low β-value indicates that a participant scored both a lot of hits and false alarms (liberal criterion) whereas a high β corresponds with a few hits and a low number of false alarms (conservative criterion). The bias can be estimated by calculating

$$\beta = Z(\text{hit rate}) / Z(\text{false alarm rate}).$$

Values of β larger than one indicate a conservative criterion. Sensitivity and bias are not defined when the hit rate and/or the false alarm rate is zero or one. Therefore the maximum hit rate is set at 0.975 and the minimum false alarm rate at 0.025.

Outliers were removed by excluding data of each participant in the screen test that had a sensitivity score in one or more of the three conditions above the mean plus 2.5 SD (2 participants) or below the mean minus 2.5 SD (1 participant). Exclusion of the results of these 3 participants only affected the average sensitivity scores marginally.

Results Experiment 1 (screen test)

Figure 6 presents the average sensitivity scores for Experiment 1 for all participants, and broken down by experts and the general public. For the analysis a two-way mixed ANOVA was used: Expertise (2 levels; between groups) x Time (3 levels; within groups). As expected, the experts performed overall much better than participants from the general public ($F(1,72)=68.54$, $p<0.001$). There was no reliable statistical evidence that the three time conditions differ from each other ($F(2,144)=2.80$, $p=0.0642$), even though there was a trend. Post-hoc t-test shows that this tendency to significance is caused by the difference between sensitivity for 500 ms and for up to 10,000 ms ($t(144)=-2.32$, $p=0.022$). However, one would expect that a longer presentation time always would lead to a better authentication result, but the average score when granted the longest presentation time (1,23) is even lower than when granted 1 second (1.26), although not significant ($t(144)=-0.76$, $p=0.450$). Most participants, both experts and public, claimed that they were basically guessing when the banknotes were presented for only 500 ms. However, they performed in fact substantially above chance level even for the shortest display duration as the average sensitivity score by the public in the shortest display duration was 0.855 which was significantly different from chance level (zero) (one sample t-test: $t(59)=10.98$, $p<0.0001$).

There is no evidence for an interaction effect between exposure time and level of expertise ($F(2, 144)= 1.65$, $p=0.1951$).

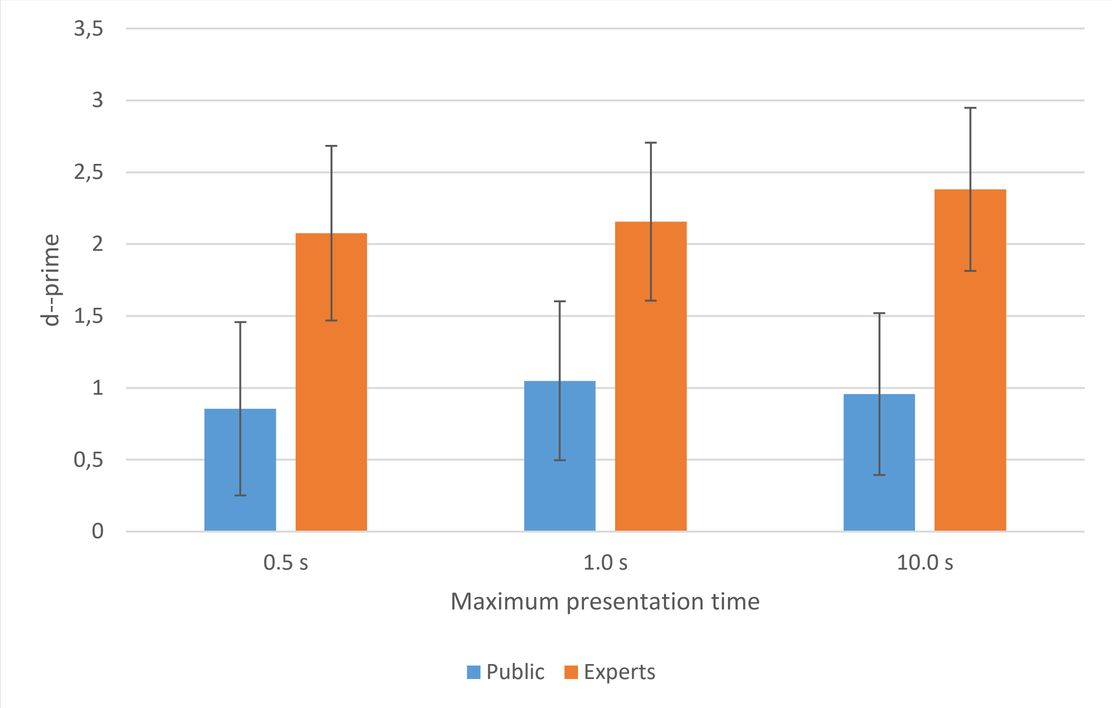


Figure 6. Sensitivity per level and exposure time: Screen condition: ***vision only***

The highest individual score on the screen test (d'=3.605) was made by one expert in the long condition (presentation time max. 10s), missing only one counterfeit. This was the composed note, which is as told partly genuine and partly counterfeit (but a counterfeit to the Eurosystem, the monetary authority of the Eurozone which is the collective of European Union member states that have adopted the euro as their sole official currency).

For each individual banknote of the test set, the percentage of recognition in all three conditions in the screen test were calculated. Multivariate analysis shows that all four main effects were significant:

- Experts (83.1% recognition) were better than the public (64.1%) ($F(1,56)=142.77$, $p<0.0001$),
- the EUR 50 was better recognized (69.3%) than the EUR 20 (65.9%), $F(1,53)=9.54$, $p=0.0032$),
- counterfeit banknotes (73.5%) were better recognized than genuine ones (64.6%), $F(1,53)=9.34$, $p=0.0035$) and
- banknotes of the second series (69.0%) were better recognized than banknotes of the first series (66.1%), $F(1,53)=7.00$, $p=0.0107$.

Furthermore, there were some interaction effects:

1. Between denomination and level of expertise, F(1,56)=5.02, p=0.0291), see Figure 7. Post-hoc tests show that the public has no different scores for denominations EUR 20 and EUR 50 (t(56)=-1.14, p=0.2609), whereas experts performed better on judging the EUR 50 (87.3%) then on judging the EUR 20 (78.9%), t(56)=-10.23, P<0.0001.

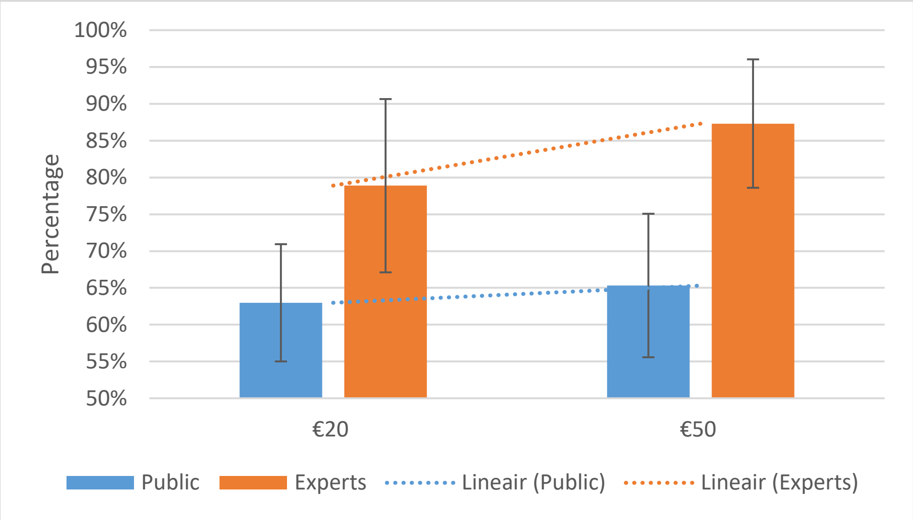


Figure 7. Percentages correct scores in Experiment 1 per level of expertise and per denomination

2. Between level of expertise and genuineness, F(1,56)=13.05, p=0.0006. Experts do not differ in their judgement when confronted with genuine or with counterfeit banknotes (T=-0.15, p=0.8783), but the public recognizes counterfeit banknotes as counterfeits much better than identifying genuine banknotes (T=-7.04, p<0.0001), see Figure 8. In other words: non-experts have the tendency to classify genuine more often as counterfeit.

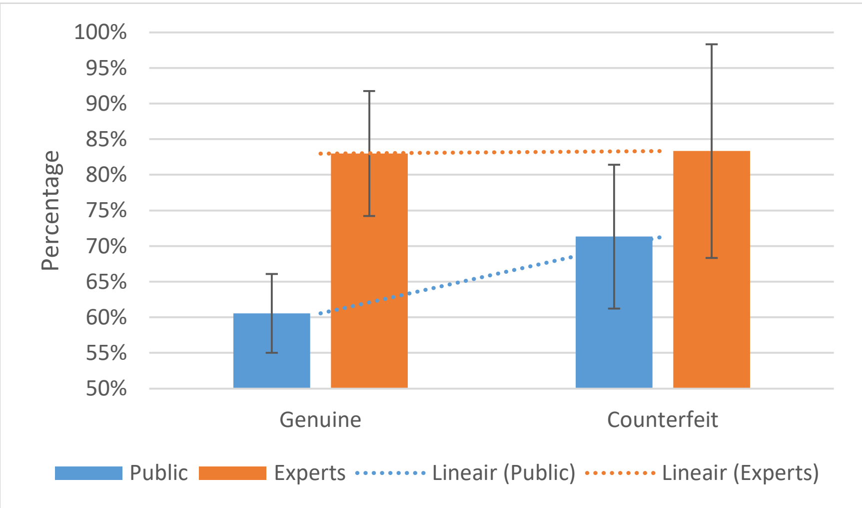


Figure 8. Percentages correct scores per level of expertise and per genuineness.

3. Between denomination and series, F(1,53)=4.48, p=0.0389. The EUR 20 of the second series is better recognized (69.0%) than the same denomination of the first series

(62.8%), T=-3.38, p=0.0014). There is no statistical evidence that there is a difference in recognizing the EUR 50 in either series. See Figure 9.

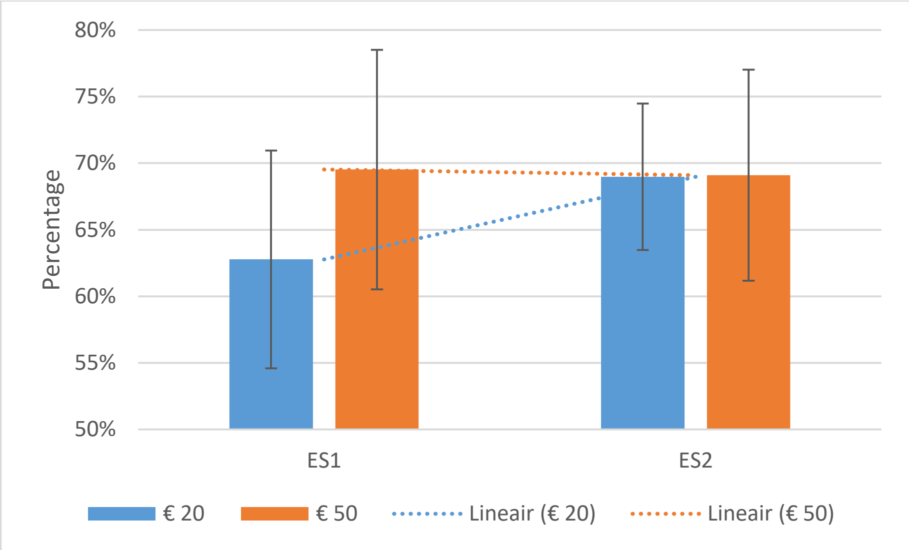


Figure 9. Percentages of correct scores per denomination and series.

1. Between series and level of expertise, F(1,56)=5.83, p=0.0190). The public did not judge the first and the second series differently (T=-0.68, p=0.5020), but the experts did (t=-10.35, p<0.0001). See Figure 10.

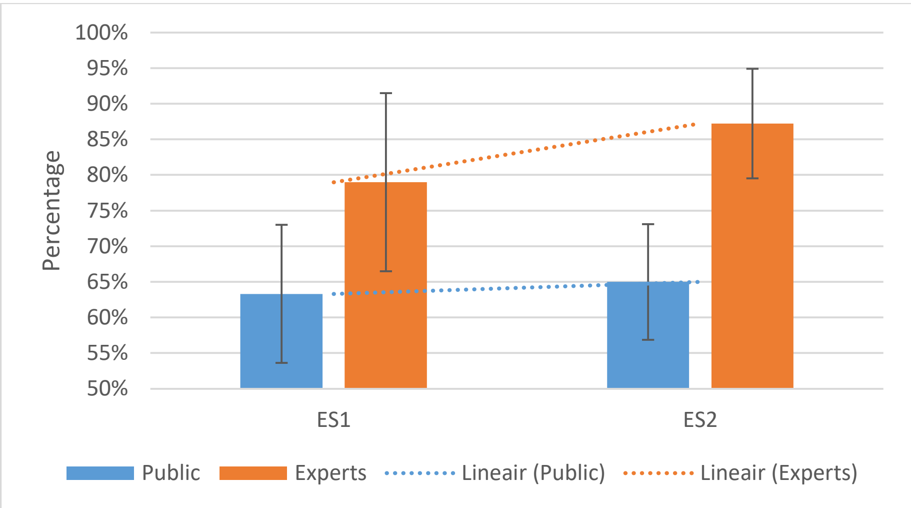


Figure 10. Percentages of correct scores per level of expertise and series.

The counterfeit that was most obvious to the public was recognized in 88% of the instances. Experts performed even better and recognized this counterfeit 95% of the time. The banknote with the lowest recognition by the public was a counterfeit that was recognized only 42% of the time. This was indeed a good quality counterfeit according to Eurosystem standards. Fortunately, experts were still able to recognize it 86% of the time. One (counterfeit) banknote was recognized by all of the experts and by 80% of the public.

The composed note was correctly identified as a counterfeit (which it is by definition, despite the fact that a part is genuine) by 38% of the experts. The participants from the general public identified this composed note in 56% of the instances as a counterfeit.

The weighted average per each individual banknote of the complete test set of the correct scores by the public and experts is shown in Figure 11. It can be seen that the lines that represent the hit rates for counterfeit scores are above those of the scores for genuine notes.

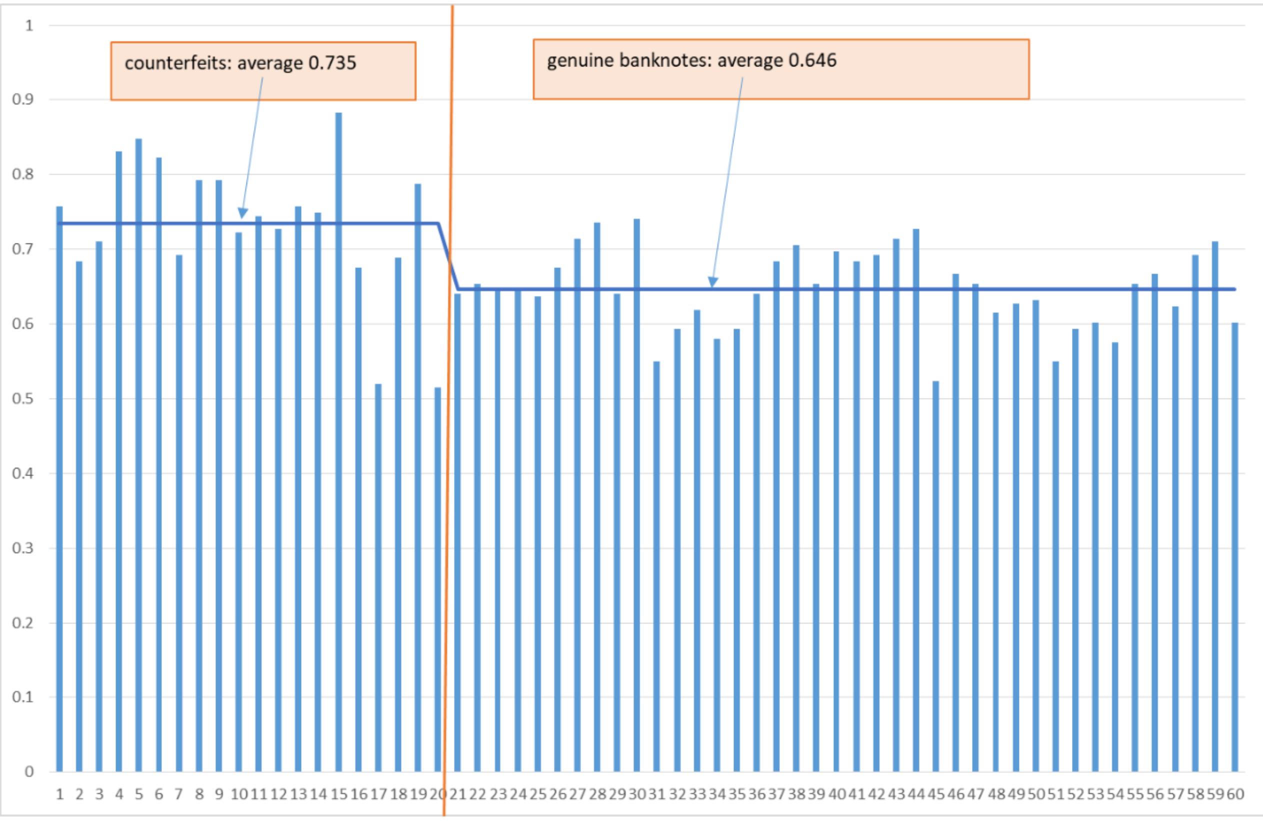


Figure 11.a. Average correct scores by the general public per banknote in the test set

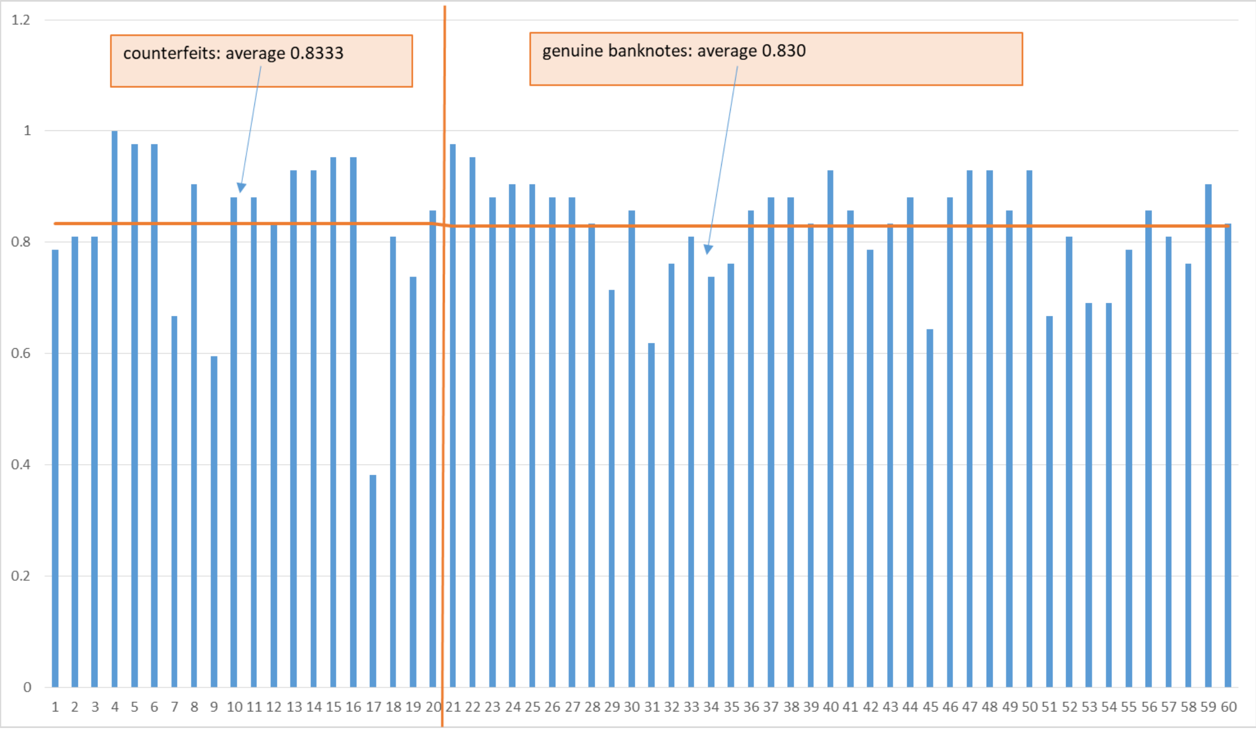


Figure 11.b. Average correct scores by the experts per banknote in the test set

Response time

Figure 12 shows the response times for public and experts, which was measured from the onset of the stimulus, in this case the banknote. We applied a 2x3x2 mixed model ANOVA on response time with level of expertise as a between and condition (display duration) and genuineness of the banknote (genuine or false) as within subject factors. The response time of the general public did not differ from that of experts ($F(1,75)=0.50$, $p=0.4806$). There was a main effect for condition presentation time ($F(2,150)=249.70$, $p<0.0001$). Longer presentation time resulted in longer reaction times. Also, there is a main effect for genuineness ($F(1,75)=13.27$, $p=0.0005$). Participants took more time to decide that it was genuine when the banknote was genuine (1.930s) than that they decided that it was counterfeited when it was in fact counterfeited (1.667s). There was interaction between display duration and genuineness ($F=8.22$, $p=0.0004$). When banknotes were presented only for a short period of time, participants took the same time to authenticate counterfeits and genuine banknotes. However, if the banknotes were presented for a longer time, they made their decision later when the displayed banknote was genuine (3,265 ms), than when it was a counterfeit (2,593 ms) ($t(150)=5.39$, $p<0.0001$). This was especially the case for experts.

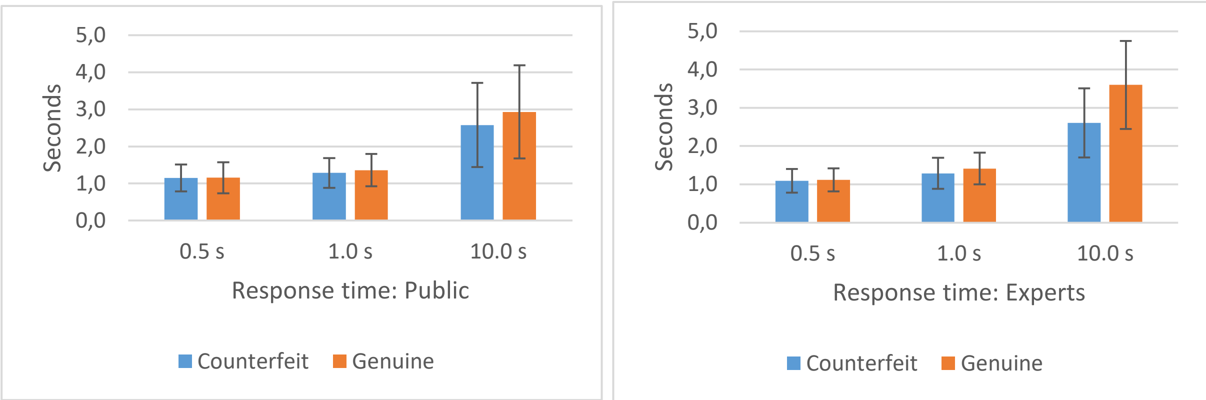


Figure 12. Response time public (left) and experts (right): Screen conditions.

Results Experiment 2 (physical test)[2]

Figure 13 shows the sensitivity scores for the public and the experts in the second experiment, in which the test physical banknotes were used. The results for the conditions feel only and look and feel, for both a short period (average time 1.3 s.) and a longer period (maximum 10s, but average 5.5) can be seen. These scores were analysed with a mixed ANOVA: Expertise (2 levels; between) x Time (2 levels; within) x Condition (2 levels; between). All main effects were significant. Experts were clearly better than participants from the general public, $F(1,36)=32,77$, $p<0.0001$. Adding seeing to only feel the banknotes is very helpful, $F(1,36)=48.72$, $p<0.0001$. The factor time is clearly of importance, $F(1,36)=9.90$, $p=0.0033$. It is clearly beneficial to be granted a bit more time to assess the banknote. Ther The lowest average sensitivity score is made by the public on the short only feel test, 0.578, but still this differs from 0 which is the value for judging by chance (one sample t test: $t(14)=2.66$, $p=0.0186$). The highest individual score on the physical test occurred both by a participant from the public and an expert, both in the long look and feel condition (d'=3.920): all banknotes were recognized. The minimum score of an individual representative of the general public was slightly negative (d'=-0.379 in the 500 ms look condition), around chance.e were no interactions between the factors.

[2] Experiment 1 involved analyses about the characteristics of the banknote, like differences in series and denominations. Due to different data gathering and fewer participants we restrained from these analysis in this experiment.

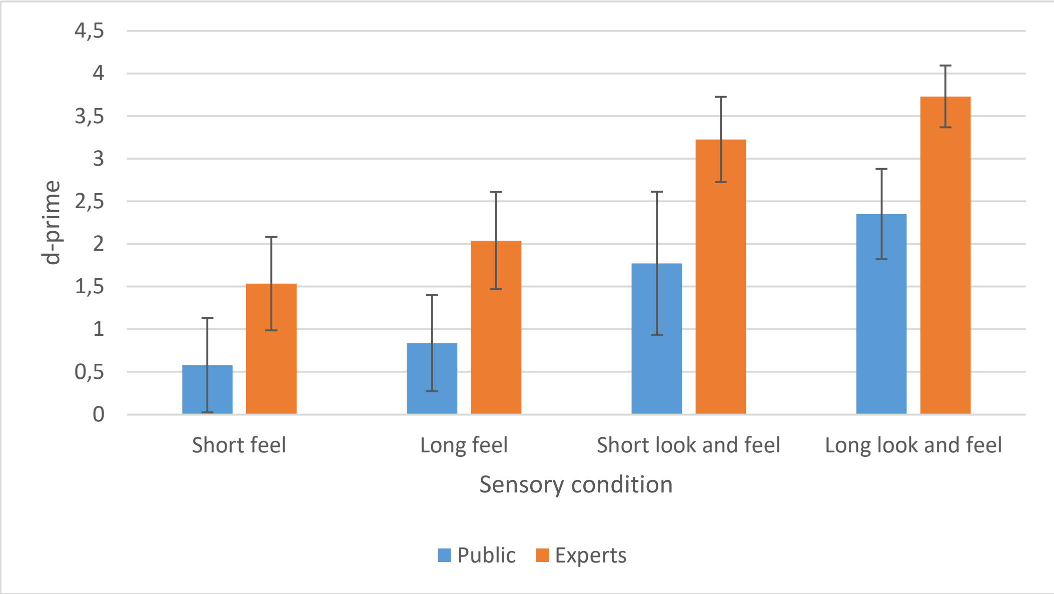


Figure 13. Sensitivity per level and handling time: Physical condition: ***feel only and look and feel***

In the physical test the time it took for each participant to handle each banknote was measured. The set-up of the experiment was intended to obtain average times that are comparable with the presentation times during the screen test. In advance it was known that the short conditions could not be as fast as the condition of 500 ms in the screen test. Therefore we aimed in the test setting for a handling time of around 1,000 ms to be able to compare later on with the 1,000 ms of the screen test. This set-up appeared to be successful, as can be seen in Table 2. A t-test showed that public and expert participants did not differ in handling time: $t(37)=0.42$, $p=0.677$). Participants took on average more time (4,380 ms) when they could only feel than when they could look and feel (2,380 ms): $t(37)=4.1773$, $p=0.0002$.

Table 2. Average handling time per condition

Public				Experts			
Look and feel		Feel		Look and feel		Feel	
Short	Long	Short	Long	Short	Long	Short	Long
1,270 ms	4,580 ms	1,420 ms	6,500 ms	1,300 ms	2,370 ms	1,340 ms	7,990 ms

Results of the combination of Experiment 1 and 2 (screen and physical test)

In this section the results of both test are combined to analyse with a three-way mixed ANOVA design, Expertise (2 levels; between) x Time (2 levels; within) x Condition (3 levels; between).

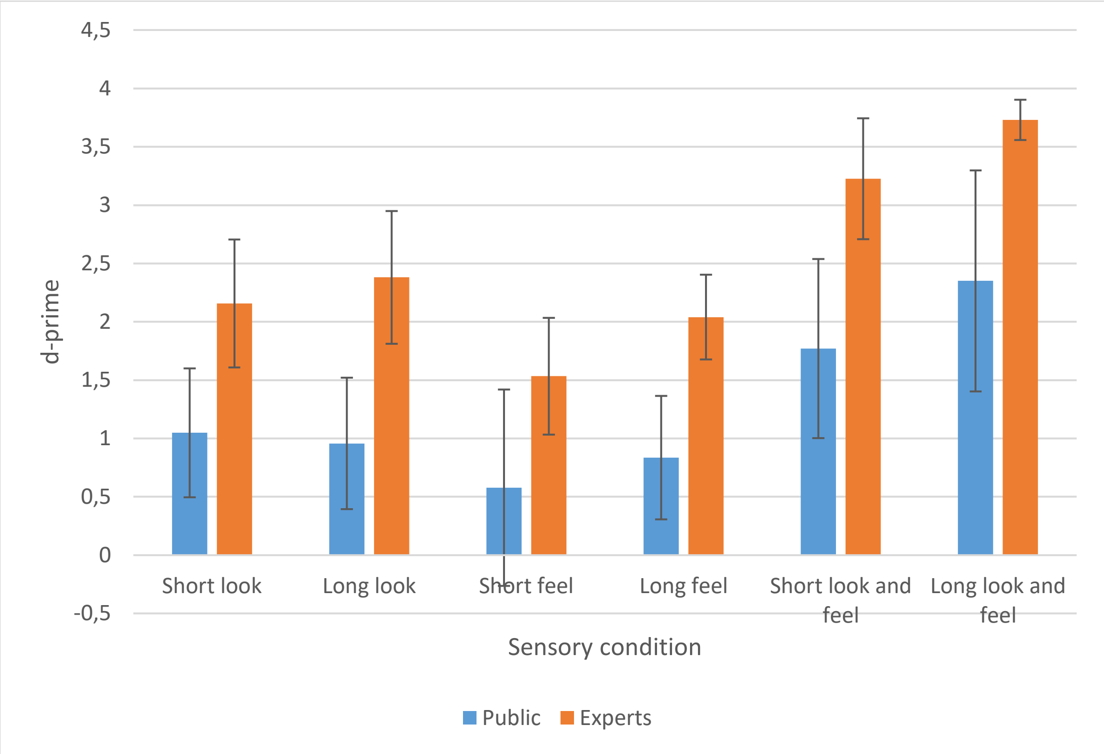


Figure 14. Authentication sensitivity per time and sensory condition for public and experts (in d'-scores).

Figure 14 displays the results. All main effects are significant. As in both experiments separately, experts are better than the general public, F(1,108)=79,10, p<0.0001. Time plays a role, F(1,108)=12,57, p=0.0006 and the results on the perceptual modality differ F(2, 108)=34.53, p<0.0001. There is an indication for an interaction between time and condition, F(2,108)=3.01, p=0.0537. This interaction is visualized in Figure 15. Post-hoc test shows that short or long looking does not result in reliable effects (t(108)=-0.63, p=0.5288). This is different for short or long feel (t(108)=-2.09, p=0.0394). Also, when look and feel are combined, time does make a difference (t(108)=-2.96, p=0.0037). Next, short look and short feel differ (t(108)=2.85, p=0.0052, but long look and long feel are statistically the same (t(108)=1.21, p=0.2304).

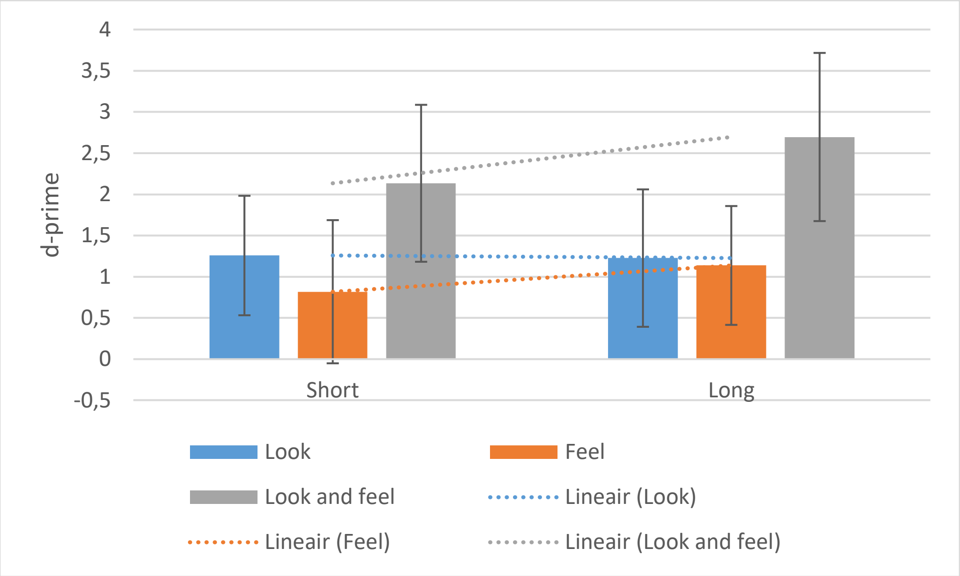
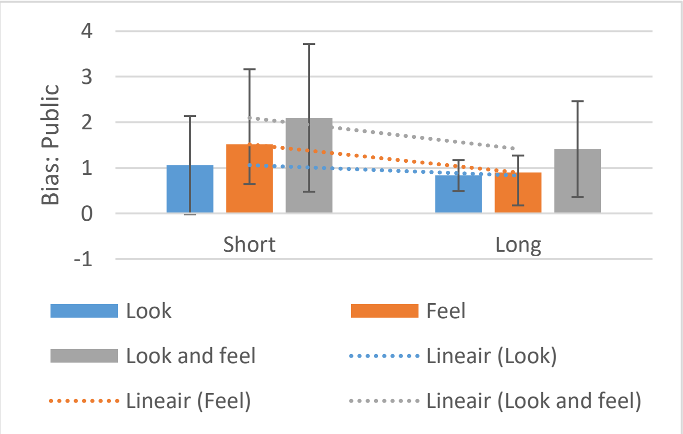


Figure 15.Sensitivity in all conditions per presentation time.

Bias

Relative to experts, the public has a different tendency to opt for one response over another, $F(1,108)=6.51$, $p=0.0121$. Participants of the general public had on average a lower β, which means that they tend to declare a banknote more often as counterfeit, resulting in more hits and more false alarms. Relative to the public experts were more reluctant to declare a banknote a counterfeit. The presentation time of the banknotes also had an influence on bias ($F(1,108)=4.35$, $p=0.0394$)). When granted only a short period of time, participants were more reluctant to judge the banknote as a counterfeit than when they had more time. The three sensory conditions impacted the bias as well, $F(2,108)=11.80$, $p<0.0001$. The look and feel condition made participants the most conservative, i.e. a tendency to declare a banknote authentic. As can be seen form Figure 16 almost all values for β are higher than one, which means that the participants employed on average a conservative criterion.



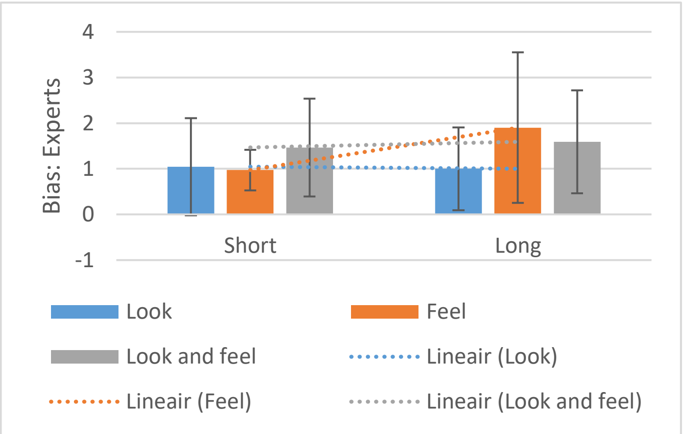


Figure 16. Bias public and experts in all conditions

Discussion

Two experiments were conducted to determine whether untrained people are able to authenticate banknotes in a brief time period or whether more time is needed, by only looking at banknotes on a screen, by only feeling the banknote or by using the combined senses touch and sight. In daily life people almost always implicitly check banknotes for authenticity, according to Type 1 processing, and seldom deliberately, according to Type 2 processing. If people were unable to authenticate according to Type 2 processing, little can be expected from implicit authentication. It is important to know if people are able to authenticate quickly, as everyday transactions do not take long. As far as it is known, it has not yet been tested how fast people can authenticate, using only sight, touch or both, without being previously instructed what to look for.

In the first experiment, images of 60 banknotes, 20 counterfeits and 40 genuine ones, all retrieved from circulation, were randomly displayed on a screen to 60 participants of the general public and to 14 experts. All participants had to authenticate these banknotes in blocks with varying display times: a maximum of 500 ms, 1,000 ms and 10,000 ms. From 'gist' literature it is known that people can make a few saccadic eye movements in 500 ms and adequately describe a scene that is presented for half a second. The question was if participants are also able to recognize whether a banknote is genuine or not in such short time. This is important as in real life the act of receiving a banknote is estimated to be around 1 second. It appeared that participants from the public do better than that they expected in advance when a banknote is presented for only half a second on a screen. They feel as if they guess, but on average the public has an average sensitivity score above chance although lower than what could be called a 'reasonably good performance' according to Raymond (2017). This is in line with the conclusion of Standing et al. (1970) that participants are unable to detect when a photograph has been mirror-reversed since this does not impact the gist. According to a study of Raymond & Jones (2019) eye movement analysis showed that the critical authenticity tells on banknotes were often missed by their participants, because of people's propensitiy to fixate areas of the note that are easily and accurately mimicked, at the expense of fixating the especially hard to mimic hologram that was less visually compelling. Raymond & Jones suggest that perception of scene gist that do not rely on precise fixational control are insufficient for authentication, at least for complex objects such as banknotes.

To increase performance during fast authenticity it is suggested to incorporate in future banknote series security features to which the eye is drawn automatically and uncontrolled, without knowing and without focal attention.

On the other hand, presentation time does not seem to be the reason why the performance is not optimal. There is no hard evidence that looking at a banknote on a screen for a (split) second results in a worse sensitivity score then looking at it for a maximum of 10 seconds.

The public recognized counterfeit banknotes as counterfeits much better than that they correctly identified genuine notes. This is not the case for experts, for whom no difference in recognizing genuine or counterfeit banknotes was found. It seems that in this experiment participants of the general public, more so than experts, have a tendency to declare a banknote more often as counterfeit, resulting in many hits and many false alarms. On the one hand this is somewhat counterintuitive, as one would expect experts to not want to miss a counterfeit, rather than wrongly calling a genuine one false. On the other hand, if one knows what to look for, as experts do, one might wait until there is certainty. Another explanation could be that people from the general public, more than experts, have a lower base level of trust, meaning that they expect to be 'tricked' by this experiment and thus expect more counterfeits than there in fact are.

The public and experts also differ on sensitivity for denominations: the experts score better when the banknote is EUR 50 than when it is EUR 20, for the public the denomination does not make a difference. A possible explanation is that experts handle more counterfeit EUR 50, as this is in the Netherlands the most counterfeited denomination and most experts in this test came from the Netherlands. Another explanation might be that the mimicking quality of the EUR 50 in the test set is lower than that of the EUR 20. Experts are also better at recognizing banknotes of the second series compared with the first, the public has the same performance for both series. An explanation for this difference has not been found.

Expert and public participants do not differ in response time, measured from the onset of the image of the banknote. The time participants take to respond to a genuine banknote is longer than for a counterfeit banknote. This is in line with a worse average score for authentication of genuine banknotes. The reason that response times are longer for genuine banknotes than for counterfeits might be that people look for proof that the banknote is fake (a 'target present' trial) and thus can stop the search task after the first deployment of attention towards such a clue. When they do not find anomalies (a 'target absent' trial) the search ends later (Wolfe, 2012) as one has to look at the whole banknote.

In the second experiment 30 participants from the public and 10 experts were randomly divided over two sensory conditions: only feel the banknotes (blindfolded) and look and feel the banknote as in real life. The test set consisted of the same banknotes of which images were presented in Experiment 1. In these two sensory conditions of Experiment 2 it was beneficial to handle the banknotes for a longer time than approximately 1 second. When touch is involved, exposure time makes a difference. A reason might be that when the banknote is handled, the banknote can be manipulated and people can look at the banknote more dynamically than when it is statically presented on a screen.

When combining the results of the first and second experiment it can be concluded that using both senses (sight and touch) gives the best performance both for public and experts. Authenticating based on only one of the senses results in far less optimal performance even though it is much better than chance. However, as said above, looking at a banknote on a screen is not the same as looking at it when the note is physically handled and can be seen in motion. Looking at a screen for a longer time does not produce a different performance than only feel a banknote in the same time. However, looking for a second gave better scores than feel for a second. The latter is in line with the results of Klein (2004) with Canadian banknotes under cashiers, where performance was better with notes that could be seen but not touched, than vice versa. In this study the banknotes were in a sleeve in the 'vision condition' and not on a screen. Klein concluded that the visual properties that can be used to distinguish genuine from counterfeit notes are more informative than the tactile properties. In that study, just as in the present one, different series and denominations were randomly intermixed. Without sight, participants would not easily know the note type. It seems possible that they might have adopted a strategy that was appropriate for only one series. There are some differences compared with the present study as well. Firstly, Canadian banknotes were used instead of euro banknotes. Next, the proportion of counterfeit to genuine notes was 1:1. Furthermore, the presentation time was not varied, and participants could authenticate to a maximum of 7 seconds. Lastly, participants in that study were professional cash handlers with more experience and knowledge than people from the general public. The study by Klein, together with the result of the present study speak against the common notion that only feeling a banknote is enough to instantly know that a banknote is fake. Hence, in future banknote design, more emphasis may need to be put on substrate selection.

The outcome that experts performed better on all tasks than the general public, may not come as a surprise. Still, the present study shows that there is room for growth for the general public in authentication capacity, perhaps by better instructing them. Furthermore, the outcome that seeing and touching the physical banknotes results in much better performance than seeing the images of them on a screen alone, suggests that it is better not to perform perception tests with new security features or whole banknotes only with the use of a screen. It also suggest that central bankers should continue to address both senses when integrating security features in new banknote series.

In conclusion, longer exposure time aids banknote authentication, although not when only seeing the banknote. On the basis of the present study, the statement of the Eurosystem that it is possible to check for authenticity in a few seconds seems to hold. It is a reassuring finding that untrained participants perform very well when they are allowed to see and feel the banknotes, for on average less than 5 seconds. Even when given only one second they perform rather well. It should be noted however, that because in the present study the prevalence of counterfeit banknotes was much higher than in daily life, the sensitivity scores that were obtained here are will also be higher than what would be feasible in daily life, because of the prevalence-effect. In daily life people rarely authenticate banknotes deliberately. However, if the system, the environment or the banknote itself is not well trusted, the general public is capable of performing such an authentication task rather well, even within a time as short as a second.

References

Bank of Italy. (2020). *Banknotes.* Retrieved from https://www.bancaditalia.it/compiti/emissione-euro/banconote.

Bank of Finland. (2020). *Recognition of banknotes*. Retrieved from https://www.suomenpankki.fi/en/money-and-payments/euro-banknotes/recognition-of-banknotes/.

Brits, H., & Winder, C. (2005). *Payments are no free lunch*. DNB Occasional Studies Vol.3/No.2.

Cabinakova, J., Knümann, F., & Horst, F. (2019). *Kosten der Bargeldzahlung im Einzelhandel.* Deutsche Bundesbank in Zusammenarbeit mit EHI Retail Institute.

Centraal Bureau voor de Statistiek Statline. (2020). *Bevolking. Kerncijfers*. Retrieved from https://opendata.cbs.nl/statline/#/CBS/nl/dataset/37296NED/table?fromstatweb.

De Heij (2017). *A Model for Use-centered Design of Payment Instruments Applied to Banknotes: Upid-Model*. Thesis. Tilburg University.

Esselink, H., & Hernandez, L. (2017). *The use of cash by households in the euro area.* European Central Bank. Occasional Paper Series. No. 201/November 2017. Retrieved from www.ecb.europa.eu.

European Central Bank (2019). *Euro banknote counterfeiting decreased further and remained low in the second half of 2018*. Press release 28 January 2019. Retrieved from https://www.ecb.europa.eu/press/pr/date/2019/html/ecb.pr190125~c64c7e8683.en.html

European Central Bank (2013). *The €5 banknote of the Europa series.* Leaflet. Version April 2013.

Fei-Fei, L., Lyer, A., Koch, C., & Perona, P. (2007). *What do we perceive in a glance of a real-world scene?* Journal of Vision, 7(1):10, 1–29, http://journalofvision.org/7/1/10/.

Frankish, K. (2010). *Dual-Process and Dual-System Theories of Reasoning*. Wiley Online Library. Volume 5, Issue 10 Pages: 830-949.

Greene, M.R., Botros, A.P., Beck, D.M., & Fei-Fei, L. (2015). *What you see is what you expect: rapid scene understanding benefits from prior experience*. Atten Percept Psychophys. Springer. The Psychonomic Society, Inc.

Healy, C. G., & Enns, J. T. (2012*). Attention and visual memory in visualization and computer graphics*. IEEE Transactions on Visualization and Computer Graphics, 18(7), 1170-1188.

Hoevenagel, R., Van Marwijk, M., Wils, J., & Bolle, H. (2015). *Contant geld: gedrag en beleving van retailers.* Prepared for De Nederlandsche Bank by Panteia. Factsheet. Available at https://www.dnb.nl/nieuws/nieuwsoverzicht-en-archief/dnbulletin-2015/dnb321621.jsp.

Kahneman, D. (2010). *Thinking fast and slow*. Farrar, Straus and Giroux, New York.

Kandula, M., Hofman, D., & Dijkerman, H.C. (2015). *Visuo-tactile interactions are dependent on the predictive value of the visual stimulus.* Neuropsychologia. 70, 358-366.

Klein R. M., Gadbois, S., & Christie, J.J. (2004). *Perception and Detection of counterfeit currency in Canada: note quality, training and security features.* Proceedings of SPIE, Optical Security and Counterfeit Deterrence Techniques V, R.L. van Renesse (ed.), Vol. 5310, 1-12.

Klöne, E-J, Vrakking, T., & Zondervan, I. (2019). *A biennial study about knowledge and appreciation of euro banknotes among the Dutch*. Prepared for De Nederlandsche Bank by Motivaction. www.dnb.nl.

Kosse, A., Chen, H., Felt, M. H., Jiongo, V. D., Nield, K., & Welte, A. (2017). *The costs of point-of-sale payments in Canada* (No. 2017-4). Bank of Canada Staff Discussion Paper.

Layne-Farrar, A. (2011). *Are Debit Cards Really More Costly for Merchants?* Assessing Retailers' Costs and Benefits of Payment Instrument Acceptance, working paper, available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1924925.
Lederman, S.J., & Klatzky, R.L. (1993). *Extracting objects' properties by haptic exploration*. Acta psychologica. 84. 29-40.
Mathôt, S., Schreij, D., & Theeuwes, J. (2012). *OpenSesame: An open-source, graphical experiment builder for the social sciences.* Behavior Research Methods, 44(2), 314-324. Retrieved from https://doi.org/10.3758/s13428-011-0168-7.
Nightingale, S.J., Wade, K.A., & Watson, D.G. (2017). *Can people identify original and manipulated photos of real-world scenes?* Cognitive Research 2 (30), 1-21. Springer.
Oliva, A. (2005). *Gist of the scene.* Neurobiology of Attention. Elsevier, Inc. 251-257.
Omrane, B., Balodis, E., & Garanzotis, T. (2018). *Lab-based perception studies: ten years of experimentation.* Optical Document Security Conference 2018. Conference proceedings.
Pérez, M, Guinea, S., & Negueruela, J.D. (2014). *The Banco de España's cash survey.* Billetaria, 16, 6-9.
Raymond, J. (2017). *The Importance of Intaglio in the Authentication of Banknotes by the General Public.* Prepared by Secure Perception Research for International Banknote Designers Association. Birmingham.
Raymond, J.E., & Jones, S.P. (2019). *Strategic eye movements are used to support object authentication*. Scientific reports. 9. https://doi.org/10.1038/s41598-019-38824-z
Rich, A. N., Kunar, M. A., Van Wert, M. J., Hidalgo-Sotelo, B., Horowitz, T. S., & Wolfe, J. M. (2008). *Why do we miss rare targets? Exploring the boundaries of the low prevalence effect*. Journal of vision, 8(15), 1–17.
Sampanes, A.C., Tseng, P., & Bridgeman, B. (2008). *The role of gist in scene recognition*. Elsevier Vision Research 48 (2008) 2275–2283.
Simons, D.J., & Rensink, R.A. (2005). *Change blindness: past, present, and future*. Trends in Cognitive Science (Regular Ed). 2005;9(1):16-20.
Simons, D., & Levin, D. (1998). *Failure to detect change to people during a real-world interaction*. Psychonomic Bulletin & Review. 5. 644-649.
Standing, L., Conezio, J., & Haber, R. N. (1970). *Perception and memory for pictures: single trial learning of 2500 visual stimuli.* Psychonomic Science, 19, 73-74.
Summers, I.R., Irwin, R.J., & Brady, A.C. (2008). *Haptic discrimination of paper.* In: Grunwald M. (eds) Human Haptic Perception: Basics and Applications. Birkhäuser Basel.
Treisman, A.M., & Gelade G. (1980). *A feature-integration theory of attention.* Cognitive Psychology 1980 Jan;12(1):97-136.
Van der Horst, F., & Matthijsen, E. (2013). *The irrationality of payment behavior*. DNB Occasional Studies 11(4).
Van der Horst, F., Eschelbach, M., Sieber, S., & Miedema, J. (2016). *Does banknote quality affect counterfeit detection? Experimental evidence from Germany and the Netherlands*, DNB Working Paper No. 499.
Van der Horst, F., Eschelbach, M., Sieber, S., & Miedema, J. (2017a). *Does banknote quality affect counterfeit detection? Experimental evidence from Germany and the Netherlands*, Journal of Economics and Statistics 237(6), 469-497.
Van der Horst, F., De Heij, H., Miedema, J., & Van der Woude, M. (2017b). *Perception of public security features on euro banknotes.* A Qualitative survey on Confidence and Authenticity. IBDA INSIGHT 13, 53-55.
Wolfe, J.M. (2003). *Moving towards solutions to some enduring controversies in visual search*. Trends in cognitive science. 7, no. 2.
Wolfe, J. M., Horowitz, T. S., & Kenner, N. M. (2005). *Rare items often missed in visual searches.* Nature, 435, 439-440.

Wolfe, J., & Van Wert, M. (2010). *Varying Target Prevalence Reveals Two Dissociable Decision Criteria in Visual Search*. Current Biology 20, 121-124.

Wolfe, J.M. (2012). *When do I quit? The search termination problem in visual search.* Nebraska Symposium on Motivation 2012; 59:183–208. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/23437634.

Wolfe, J.M., & Horowitz, T.S. (2017). *Five factors that guide attention in visual search*. Nature Human Behaviour, 1, p.58.

Wijntjes, M.W.A. (2009). *A technical feel model for banknote design based on a literature review.* Study ordered by De Nederlandsche Bank NV and European Central Bank. Unpublished. Delft University of Technology. Faculty of Industrial Design. Delft.

Zondervan, I., Heinen, H. & Heuvel, E. (2019). *Cashier field study pilot.* Prepared for De Nederlandsche Bank by Motivaction. Unpublished.

Annex Instruction form (translated from Dutch)

Instructions for study Instant or in hand: physical part

To be read out by the test leader

< introduction and welcome >

Thank you very much for participating in this test to recognize counterfeit banknotes. One of the most important tasks of De Nederlandsche Bank is to issue banknotes that are difficult to counterfeit. By participating in this test, you can help us learn more about how good Dutch people are at distinguishing between genuine and counterfeit notes.

You will soon be handed several notes one by one. Most notes are real, but a considerable number are fake. After receiving the note, your task is to put the note in the container on your right and then indicate whether you think it is real or fake.

< *for feeling conditions only*: We would like to know if just feeling a note is enough to recognize whether it is genuine. That is why we ask you to put on this sleep mask for the.>

There are two conditions:

- In what we refer to as 'the long condition' you will be given a maximum of 10 seconds to assess the ticket. At the latest when the bell rings, you put the note away, but you may also put it away earlier. Then you say whether you think it is real or fake.
- In what we call 'the short condition' you will be handed the note, and you must put it in the container in one fluent movement. Then you have to say whether you think it is real or fake.

After you have assessed all the notes, we will tell you how many genuine and fake notes you correctly identified.

At the end of this survey, you will receive a short questionnaire. Your personal data cannot be traced back from this, the information will only be used for general statistics. The form with these questions will soon be given to you.

To give you some idea of what is expected, we will first do a practice session with 6 notes. The outcome of this session will not be included in the final result, it is just intended to make sure everything works and is clear.

Do you have any questions?

Ok, if everything is clear then we'll start the practice session now, good luck!

Previous DNB Working Papers in 2020

No. 662 **Carin van der Cruijsen-Knoben, Jakob de Haan and Ria Roerink**, Financial knowledge and trust in financial institutions
No. 663 **Jon Frost,** Economic Forces Driving FinTech Adoption
No. 664 **Anna Samarina and Nikos Apokoritis,** Evolution of monetary policy frameworks in the post-crisis environment
No. 665 **Christian König-Kersting, Stefan T. Trautmann and Razvan Vlahu,** Bank instability: Interbank linkages and the role of disclosure
No. 666 **Claus Brand, Gavin Goy, Wolfgang Lemke,** Natural Rate Chimera and Bond Pricing Reality
No. 667 **Joost Bats,** Corporates' dependence on banks: The impact of ECB corporate sector Purchases
No. 668 **Marc van Kralingen, Diego Garlaschelli, Karolina Scholtus and Iman van Lelyveld,** Crowded trades, market clustering, and price instability
No. 669 **Mark Mink, Rodney Ramcharan and Iman van Lelyveld,** How Banks Respond to Distress: Shifting Risks in Europe's Banking Union
No. 670 **Jasmira Wiersma, Rob Alessie, Adriaan Kalwij, Annamaria Lusardi and Maarten van Rooij,** Skating on thin ice: New evidence on financial fragility
No. 671 **Michiel Bijlsma, Carin van der Cruijsen and Nicole Jonker,** Consumer propensity to adopt PSD2 services: trust for sale?
No. 672 **Duncan van Limbergen and Robert Vermeulen**, The importance of value chains for euro area trade: a time series perspective
No. 673 **Martijn Boermans en Bram van der Kroft,** Inflated credit ratings, regulatory arbitrage and capital requirements: Do investors strategically allocate bond portfolios?
No. 674 **Andras Lengyel and Massimo Giuliodori**, Demand Shocks for Public Debt in the Eurozone
No. 675 **Raymond Chaudron, Leo de Haan and Marco Hoeberichts,** Banks' net interest margins and interest rate risk: communicating vessels?
No. 676 **Martijn Boermans and John Burger**, Global and local currency effects on euro area investment in emerging market bonds
No. 677 **Patty Duijm and Ilke van Beveren**, Product diversification as a performance boosting strategy? Drivers and impact of diversification strategies in the property-liability insurance industry
No. 678 **Richard Heuver and Ron Berndsen,** Liquidity Coverage Ratio in a Payments Network: Uncovering Contagion Paths
No. 679 **Gabriele Galati, Jan Kakes and Richhild Moessner,** Effects of credit restrictions in the Netherlands and lessons for macroprudential policy (not published yet)

DeNederlandscheBank
EUROSYSTEEM

De Nederlandsche Bank N.V.
Postbus 98, 1000 AB Amsterdam
020 524 91 11
dnb.nl