Factors affecting the probability of detecting a counterfeit banknote

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attitude, situation and design

VRIJE UNIVERSITEIT

FACTORS AFFECTING THE PROBABILITY OF DETECTING A COUNTERFEIT BANKNOTE

attitude, situation and design

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"*The simple act of paying attention can take you a long way.*"

– Keanu Reeves –

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Introduction

1.1 Focus of thesis

Like everything of value, cash money has been counterfeited since its introduction into the economy (Boeschoten & Van Loo, 1984). This started well before the large scale introduction of banknotes, when gold or silver coins were targeted by filing or trimming the coin edges. This was made practically impossible at an early stage by the introduction of serrated or inscribed coin edges. Nonetheless, various other methods of counterfeiting continued to exist, and this led to a large part of the circulation consisting of low-grade coins. According to Boeschoten and Van Loo (1984), an important reason for the growing willingness of the nineteenth-century public to accept the initially-so-mistrusted banknotes was that they were safer than coins. With the gradual disappearance of gold and silver as coin metal and the replacement of the larger coin values with banknotes, the counterfeiting of coins, compared to banknotes, has come to play a negligible role nowadays. Instead, counterfeiters' focus—and thus the focus of this thesis—has turned to paper money.

The general public can be misled with a counterfeited banknote even if the quality of the imitation is far from perfect (Deutsche Bundesbank, 2020). As people generally do not expect that something might be wrong during a cash transaction, they do not question the genuineness of a banknote and tend to accept it automatically. The aim of this thesis is to provide insight into what kind of triggers may induce a person to leave the 'autopilot mode' and devote more attention to a banknote during a cash transaction, with the specific goal of evaluating and authenticating it. I will reflect on how these triggers can be originated within the receiver of the banknote, by the environment where the cash transaction takes place, or by the banknote itself. Once suspicion about a banknote's genuineness is raised, a deliberate authentication processing will start.

This thesis proposes a new dual processing model for evaluating and authenticating banknotes (Chapter 2), and it empirically tests the plausibility of parts of this model (Chapters 3, 4, 5). The model is applicable to banknotes in general, although the focus in this thesis is on euro banknotes. Guided by the model, I provide suggestions on what could be an appropriate attribute of a security feature, in terms of improving cash handlers' confidence, guiding attention and being self-explanatory.

An overarching and more practical aim of the thesis is what is generally considered the core of central banks' cash policies: contributing to maintaining trust of the general public in banknotes in general. It is meant to aid central banking authorities in their task to promote a safe and reliable payment system, and ultimately to aid the general public in the prevention of counterfeit losses. Note that counterfeit losses are not reimbursed (European Central Bank, 2022a). The counterfeiting of banknotes and coins is and has been considered a serious crime, because ultimately it can lead to mistrust in the cash payment system. An extreme example of a reaction to such a concern can be found in Chinese banknotes in the early Ming dynasty, which carried the message that counterfeiters would be beheaded (Kranister, 1989). Such extreme punishments are not the case anymore. However, knowingly paying with counterfeit money in the Netherlands can still lead to prison sentences of up to nine years (Scholten, 2017).

In the remainder of this Introduction, I will first describe the key cognitive concepts that are used in the thesis: *perception, attention and decision-making*. Next, I acquaint the reader with the central stimulus and main item of interest: the euro banknote. I then profile the human agents involved (counterfeiters and general cash handlers), before concluding with an outline of the main body of the thesis.

1.2 Theoretical framework

Accepting or rejecting a banknote during a cash transaction, like accepting change from a retailer or in a mutual transaction, is behaviour involving (higher-order) cognitive processes, involving perception, judgement (the assessment of the authenticity of a banknote) and decision-making (the actual acceptance or rejection of the banknote). The outcome of the judgement and decision process can vary, for instance when a low-denomination banknote is considered a forgery, and the receiver does not want to endanger the relationship with the giver of the banknote and decides to accept the banknote even though it is clearly counterfeited. In the present section, relevant theories on decision-making and perception are discussed.

Judgements and decisions are largely computed on the basis of incoming sensory input. Schaede and Lohweg (2006) argue that the two main communication channels for the recognition of banknotes are evidently the visual (seeing the banknote) and the tactile (the feel of the paper or raised ink) channel. The discussion in this thesis is limited to these two of the five senses, although one could even think of the auditory perception of banknotes (e.g., banknotes may have a specific 'crispy' sound when being bent or folded). There have even been attempts to train animals or produce devices that 'sniff' banknotes, but so far these have not been very successful and are moreover not aimed at human perception (Gasera, 2022).

1.2.1 Vision

Within the context of visually recognizing counterfeits, it is important to know how much information a handler of a banknote receives and processes in a short time. After all, the average cash transaction is relatively brief. Thus, within the realm of vision, let us review what is known about processing and recognition in a single glance.

A single glance of a scene, generally ranging from 13 ms to 250 ms (milliseconds) in presentation duration, is generally enough to gain a conceptual understanding of the scene (e.g. a football match), the spatial layout of the environment and the identity of a few objects. This initial representation of a scene that can be obtained in a brief glance is called the 'gist' of a scene (Malcolm, Groen & Baker, 2016). The gist can be reached within a single glance of less than 200 ms (Fei-Fei, Lyer, Koch & Perona, 2007). With duration longer than 200 ms, it is possible to make saccadic eye movements in which the centre of gaze is shifted to another part of the visual field. In order to gain information beyond gist – whether to support detailed recognition, search or to authenticate a banknote – eye movements are essential. According to Fei-Fei- et al. (2007), observers need 500 ms to categorize outdoor and indoor scenes. Their study showed 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. Two or three saccadic movements can be made in a second. Several factors determine whether the eyes are guided during search. This is the result of a bi-directional relationship between scene properties, ranging from low-level features to high-level semantics, and the viewer's goals (Malcolm et al., 2016). In most cases, cash transactions are handled fast, generally within a second. If the receiver does not have the intention to authenticate, the banknote will probably only be seen in motion. Most likely, the only visible information that will be processed will be its colour, size, the numeral (value) and possibly the main image of the banknote. This implies that during a cash transaction on autopilot, visually not much more will be derived than what we can call the gist of the banknote.

Acquiring the gist of a scene (or other global properties) may thus in itself not be enough to authenticate complex objects such as banknotes, even though the gist constitutes a critical component of object recognition and oculomotor guidance mechanisms (Raymond & Jones, 2019). Nevertheless, it is important to understand how people use vision to identify specific global objects in a world full of distractors. Treisman and Gelade (1980) proposed the Feature Integration Theory (FIT) that involves a preattentive stage (vision before attention) in which specific features of objects are processed at the same time (in parallel) to produce a representation that encodes not only their locations but also the basic visual properties of the stimulus such as colour, orientation, motion etc. These feature representations are activated more or less automatically as part of early visual processing and before conscious awareness. According to FIT, this phase is followed by the attentive phase in which the features of objects are bound together, one object at a time (i.e., serial object recognition).

With respect to banknotes, the above may imply that visual processing is mainly dependent on quick, pre-attentive processing of 'free-floating' features. After all, as argued by Treisman and Gelade, targets defined by unique features can be detected in parallel—and early on—as they are assumed to pop out of the background.

1.2.2 Touch

As noted, security features in banknotes also appeal to touch. Perception through touch (haptics), refers to the identification of the characteristics of objects, like a banknote, on the basis of contact between the object and the skin. Haptic identification of a wide range of objects can be remarkably fast and accurate (Klatzky, Lederman & Metzger, 1985). When people want to identify objects haptically, they make use of exploratory procedures, like lateral motion, applying pressure, enclosure and contour-following. The subject properties that can be explored are size, weight, contour, surface and material characteristics, consistency and temperature (Lederman & Klatzky, 2009).

Wijntjes (2009) established in a study commissioned by De Nederlandsche Bank (DNB) that a cash handler who 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 backside 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 1-1. The picture on the left shows the bending of the banknote, the picture in the middle shows the planar movement of the thumb and the picture on the right shows the multiple contact areas. The cash handler thus uses their fingertips to perceive various banknote properties such as the feel of the paper and raised ink.

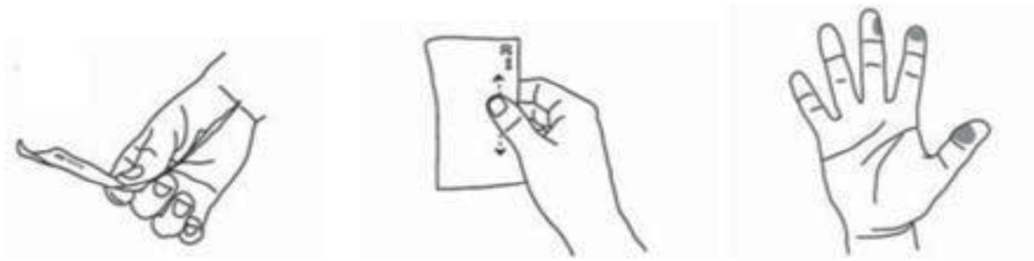

Figure 1-1. Haptic banknote interaction. Left: movement over the surface. Bending of the banknote, fingers on two sides. Thumb on the front and index finger on reverse. The middle finger is sideways supporting the index finger. Middle: multiple contact areas. Thumb (and not index finger) is used to rub 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 and van den Heuvel (2019) carried out an in-house study for DNB in which two 'mystery shoppers' purchased a product at 30 shops and paid with an artificially modified genuine banknote. The retailers' behaviour 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. The studies by Zondervan et al. and Wijntjes focused on pro-active haptic exploration by retailers. It is also worth determining how banknotes are received by the typical cash handler, i.e. without conscious exploration. A study by Lingnau, Pavani and Schwarzbach (2007) showed that the centre-left and right parts of the banknote are touched the most (Figure 1-2).

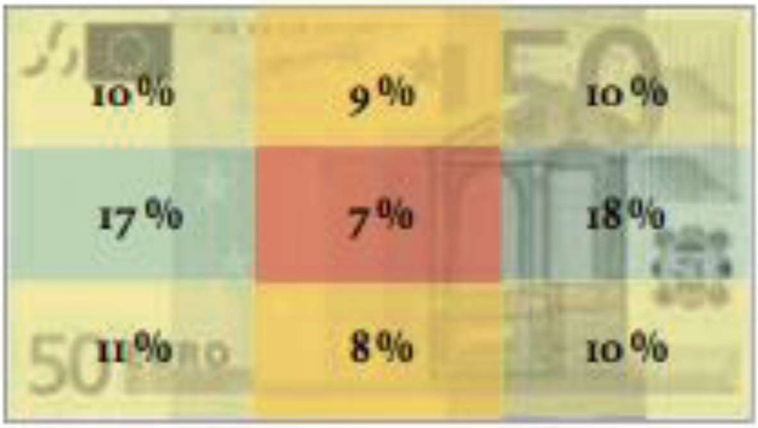

Figure 1-2. Relative frequencies of locations touched. Source: Lingnau, Pavani, & Schwarzbach, (2007). How do people manipulate banknotes? Research conducted for ECB by Centre for Mind/Brain sciences. Adapted from de Heij (2009).

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 & Klatsky, 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 have just received when 'it feels different'. In line with this, the European Central Bank (ECB) recognizes that the feel and touch of a banknote are important features for detecting counterfeits. The feel includes the paper ('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). In general, the ink layer of the banknote is up to about 60 μm thick. However, this thickness decreases when banknotes are used extensively. According to de Heij (2017), deterioration of banknotes is caused by relaxation of the paper fibres, 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 test and discriminate between banknotes based on 'intaglio only' (raised ink). The banknotes were specifically manufactured for this study. Respondents had to learn about these novel notes and the counterfeits. Raymond (2017) used three soil levels and three variants of counterfeits, similar to what is seen in actual counterfeits. The results showed that counterfeit detection sensitivity 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. It was concluded that intaglio (raised print) provides a distinctive look and feel to notes that are not easily mimicked by using other printing techniques. People who used their fingers in an exploratory way when inspecting the new note at the beginning of the study ('tactile explorers') were better at counterfeit detection in general.

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

As the present thesis outlines the factors contributing to counterfeit detection, one important issue to address concerns the relative contribution from visual and haptic perception in the authentication process. Multi-sensory authentication of banknotes has only been previously investigated by Klein, Gadbois and Christie (2004). In subtests of this study, the objective was to compare the 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 a screen blocked their view of the notes. 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 92% on average.

In line with Klein et al. (2004), to quantify the importance of tactile discrimination in counterfeit detection, in the study described in Chapter 4, we included a condition in which participants could only feel the banknote. Comparing this condition with a 'see only' condition allowed us to quantify the importance of tactile information. Finally, the experiment also comprised a condition combining vision and touch, which is more equivalent to real-life transactions. Consistent with Klein et al., our study shows that only feeling a banknote is not enough to instantly know that a banknote is a counterfeit. Vision is crucial for a thorough authenticity check. However, consistent with Klein et al. best performance was obtained with using both tactile and visual characteristics.

1.2.3 Attention

In the process of banknote authentication it is important that people prioritize and attend those regions of the banknote containing security features. So what could be helpful to direct the attention to these important regions?

Salience, i.e. the perceptual strength of an input based purely on stimulus attributes (Shinn-Cunningham, 2008) is a way to guide attention towards these important regions. According to Wolfe and Horowitz (2017), there are probably two dozen attributes that guide attention, some of which are under discussion. Undoubtedly, guiding attributes include colour, motion, orientation and size, and to this list one might add shape, closure and pictural depth cues.

The Feature Integration Theory is useful because it seeks to explain how organisms integrate features of objects in the overall perception of that object. Nowadays, researchers agree that attention plays a critical role in what we see, even at an early stage of visual perception (e.g. Healey & Enns, 2012). Nevertheless, the term pre-attentive is still often used, because it provides a notion of the speed and ease with which individual properties or features are identified. Pre-attentive processing can help to rapidly draw the focus of attention to a target with a unique visual feature (i.e., little or no searching is required in the pre-attentive case). Finding a target that is presented among other elements and that is only presented less than 200-250 ms, is generally considered to be "pre-attentive" (Healey & Enns, 2012). However, finding a target in complex real-world scenes typically requires exhaustive, serial search with search times possibly up to 3 to 4 sec (see for instance Oliva, 2005; Fei-Fei et al., 2007). Chapter 4 describes experiments in which participants had to detect counterfeits in displays presented for 500 ms (van der Horst, Snell & Theeuwes, 2020). This can be considered "pre-attentive plus", as it is longer than purely pre-attentive search but substantially shorter than what one would expect for serial search. Chapter 5 describes experiments in which we tried to improve counterfeit detection by means of introducing salient cues (van der Horst, Snell & Theeuwes, 2021).

Having emphasized the importance of attention in banknote authentication, let us now turn to what is known about attention itself. Our brain capacity is limited and it is impossible to process everything that reaches our senses. Therefore, some information needs to be prioritized over other information. Selective attention determines what will be processed and which information will be ignored (e.g. Murphy, Groeger, & Greene, 2016). Attention research began in 1958 with Broadbent's pioneering 'filter model', which proposed that perceptual processes leading to object recognition require focused attention. According to the load theory of attention and cognitive control (Lavie & Dalton, 2014), the perceptual system has limited capacity and must therefore be protected from overload by an attentional filter that excludes or weakens the processing of unattended information at an early stage of processing. If a task demands more capacity than is available, task-irrelevant items are not processed and can therefore be ignored. The most important function of attention is thus selectivity, which refers to a process by which attention is focused on an input while ignoring other input (Lavie & Dalton, 2014).

A well-known example of selective attention is the so-called 'cocktail-party effect' which demonstrates that people attend to all sensory information at some level (Conway, Cowan & Bunting, 2001). The phenomenon involves a situation where you are busy talking to a friend at a cocktail party. While talking with the friend, the many other sounds in the room are typically not consciously registered (e.g., you are entirely not aware of the conversation about Kim Kardashian occurring a few metres away, even though the sound waves produced by the people having that conversation do reach your eardrums). Suddenly, however, you hear your name mentioned by somebody in a nearby group. This is clearly of interest and will cause you to shift attention away from the friend and to the group where your name was mentioned. The ongoing task, in this case, talking to a friend, is ignored when a more interesting task interrupts.

While anecdotally sound, there are a few constraints on the notion that we always remain receptive to 'external' information. Indeed, an often-cited phrase by Kahneman (2011) is that 'it is possible to do several things at once, but only if they are easy and undemanding' (p. 23). For instance, one can drive a car in a familiar area and at the same time have some small talk with a passenger; but it is almost impossible to have a conversation about politics while at the same time parking a car in a tiny parking spot. The phenomenon of 'inattentional blindness' describes the situation where one is focusing intensely on a task and then becomes 'blind' to visual stimuli that normally attract attention. A well-known demonstration of this can be seen in a video made by Simons and Chabris (1999). Participants were asked to count silently how many times three basketball players wearing white shirts passed the ball. After about 40 seconds, a woman in a gorilla suit enters the scene, faces the camera, thumps her chest and walks away, spending a total of 5 seconds on the screen. Typically, in these type of experiments about half of the viewers do not perceive the gorilla. In fact, some people looked right at the gorilla yet did not seem to notice it. Participants that were not required counting the passing of the ball, were more likely to notice the gorilla. It can be concluded that when the perceptual load is high, it is less likely that one can process all information across the visual field. Note however, whether or not 'external' information is consciously registered, is not only a function of the perceptual load, but also depends on the salience of the external stimulus (e.g., your own name is salient enough to trigger the cocktail-party effect; and if the woman had worn a bright pink gorilla suit, she would be noticed without a doubt).

According to Wolfe and Horowitz (2017), attention can be guided in five different ways. First, attention can be guided *bottom-up*, which can be defined as stimulus-driven guidance in which the visual properties of some aspects of the scene attract more attention than others. The extent to which an object is capable of capturing attention in a stimulus-driven way depends on the saliency of the object (Theeuwes, 1991, 1992). The saliency of an object depends on two factors: local feature contrast (Nothdurft, 1993) and distractor-distractor similarity (Duncan & Humphreys, 1989). Local feature contrast refers to how different an item is from nearby items (Nothdurft, 1993). Distractor-distractor similarity refers to the variation within a display or scene. With a high homogeneity of the distractors, the element that is different from the distractor is more likely to pop-out and capture attention (Wang & Theeuwes, 2021). With respect to banknotes this would imply that security features surrounded different elements (local feature contrast) in banknotes that are somewhat homogeneous are more likely to grab attention.

The second type of guiding is *top-down*, which can be defined as user-driven guidance in which attention is directed to objects with known features of desired targets. Thus, knowledge about the location and existence of relevant security features is helpful when one wants to authenticate. This was recently shown in a study by Stevanovski and Klein (2022). In their experiment, participants inspected banknotes from seven regions (Canada, Norway, Taiwan, United States of America, Japan, and European Union), while eye movements were recorded. Participants received three different conditions: to look as if the banknotes were works of art, to examine whether they were counterfeit, or to look at them and try to remember details about the layout. In general, there were many eye fixations towards eyes and faces of the portraits shown on the banknotes. However, the amount of attraction towards the eyes and faces was strongly affected by context. When participants were asked to think about the 'counterfeit?' question, they looked considerably less at these features. Instead, security features were attended more in the Counterfeit condition than in the Art or Layout condition. Note however that the overall dwell time inspecting the security features was relatively low. Similarly, Raymond and Jones (2019) concluded that those participants that are successful at banknote authentication direct their gaze toward areas known to provide useful authentication cues and away from areas that are less informative.

The third guiding principle is scene-guidance, in which attributes of the scene guide attention to areas likely to contain targets. With respect to banknotes this would imply that it should be possible to design banknotes in which the image of a banknote guides the eyes towards to areas within the banknote that are likely to contain security features. With a design like this one should be able to finding security features faster than when the image of a banknote does not provide any guidance.

The fourth way of guidance is based on the perceived value of some items or features. For example, if it is rewarding to look at a particular security feature because it is attractive or appealing, it is likely that people would look at it more often.

The fifth way to guide attention is based on the history of prior searches (see also Theeuwes, 2019). Experience with banknote authentication helps in directing attention to locations and features that have been selected before. All of these guiding principles can apply to banknote authentication. However, the main focus in this thesis is on the first two guiding principles: top-down guidance, referring to deliberate, conscious search to features and objects that provides clues about the authenticity of a banknote, and bottom-up capture, referring to attributes of the banknote that are so salient that they demand to be looked at.

It is key to realize that it is not only important to detect the presence of security features, but even more so to detect when security features are absent. In case of counterfeited money the security feature may not be present or less visible or detectable than a genuine security feature. Several studies have shown that search times for so-called target-absent conditions are much higher and that target-absent tasks result in more errors than target-present tasks. Obviously, detecting the absence of something requires exhaustive search and one is never one hundred percent certain that something is absent, thus generating more errors (e.g. Lewandowski, 1996). Another issue is the so called prevalence effect referring to the finding that one is more likely to fail to detect a target with a low prevalence than a target with a high prevalence. Wolfe, Horowitz, and Kenner (2005) demonstrated that, in complex displays, when the prevalence of a target is low, participants are surprisingly poor at detecting it. In their experiment, observers had to search for a target (a tool), in displays with semi-transparent objects placed randomly against a noisy background. When the target was present in 50% of trials, participants made few 'miss' errors (7% of target-present trials). In contrast, at 1% prevalence, errors increased dramatically to 30%. These errors were almost all 'misses' (i.e. not noticing a target). 'False alarms' (saying that a target is present, when in fact it is absent) were extremely rare (0.03%). In addition, reaction times (RTs) for target-absent responses were much faster at 1% than at 50% prevalence. With infrequent targets, observers typically say "no, not present", and most of the time this is correct.

1.2.4 Judgement and Decision-making

In the previous sections, we saw how properties of our senses and higher cognitive processes determine how we perceive and attend to our environment. People take decisions accordingly, although they are not always the best decisions. People like to think that they are rational and in control of their decisions. However, there is a whole range of studies showing that people mostly judge and decide unconsciously and irrationally. Ariely (2010) conducted an experiment where volunteers were given electric shocks in order to test the effectiveness of painkillers. In advance, the participants were told that a painkiller would lead to significant pain relief in 92% of patients receiving the painkiller. However, it was not revealed to the participants that the painkiller in fact was a placebo (vitamin C). When told that the drug cost $2.50 per dose, nearly all of the subjects reported pain relief when shocks were administered (experiments like these were still possible in those days). When told that the drug cost $0.10 per dose, only half of the subjects reported pain relief. This study suggests that we construct percepts based on experience and expectation, and we expect that expensive pills should give a stronger pain relief.

When a rational decision can be seen as maximizing benefits in general (Katona, 1953), an example of an irrational decision is that people respond differently to dilemma's that have the same outcome, but are framed differently. People tend to be risk-averse for gains and risk-seeking for losses. Tversky and Kahneman (1981) asked two groups of participants to imagine that an Asian disease would cause 600 deaths in the US. The participants had to make a choice between two possible intervening programs. Group 1 had to choose between either (1) If Program A is adopted, 200 people will be saved or (2) If Program B is adopted, there is 1/3 probability that 600 people will be saved, and 2/3 probability that no people will be saved. When confronted with this choice, 72% of the participants preferred program A. Another group of respondents to choose between: (1) If program C is adopted, 400 people will die, or (2) If program D is adopted, there is 1/3 probability that nobody will die, and 2/3 probability that 600 people will die. For this group of participants 78% chose Program D. Thus when the choice was framed in terms of gains, i.e. lives saved, most people opted for the certain outcome, but when the identical choice was framed in terms of losses, i.e. lives lost, most people avoided the option of the certain loss. This framing effect occurs without much, if any, awareness and is considered a bias or manifestation of an heuristic or simplifying shortcurt of intuition (Kahneman, 2011). Since every day we need to process a lot of information, people use mental unconscious shortcuts or heuristics, to simplify information processing and decision making. Wherever possible, people avoid the mental effort required for cognitive reasoning. Unfortunately, these heuristics often fail to produce a correct judgement, and can lead to irrational decisions.

The prevailing view is that people use two types of cognitive processing strategies: one fast and intuitive, making use of heuristics, the other slow and deliberative. Automatic activities that are attributed to the first type of processing include, for instance, detecting that one object is more distant than another, or understanding a simple sentence (Kahneman, 2011). The second type of processing requires dedicated attention, for instance when consciously authenticating a banknote.

Stanovich & West (2000) and Kahneman (2011) have labelled these two types of decision-making as System 1 and System 2, but other labels have also been used. System 1 comprises innate skills such as recognizing objects, but also fast and automatic mental skills that people have acquired through extensive practice such as reading. The operations of System 2 are highly diverse, but all of them require conscious attention. In order to understand these constructs in full, the following aspects must be considered. First, as noted by Evans and Stanovich (2013), the use of the term dual systems implies that two separate parts in the brain are responsible for these processes. However, human cognition is not organized in distinctly separated physical systems (Djulbegovic, Hozo, Beckstead, Tsalatsanis, & Pauker, 2012). Indeed, the term System 1 should be plural as it refers to a set of autonomous systems in the brain and not to just one system. Because of this, Djulbegovic et al. (2012) use the term 'Type' instead of 'System'. In this thesis I also employ the term 'Type'.

Second, there is some discussion regarding the exact defining features. Evans and Stanovich (2013) defined Type 1 processing by two features: firstly, it does not require working memory; and secondly, it is autonomous in the sense that it is not under the control of Type 2 processing. Type 2 processes, on the other hand, do require working memory. Other defining features of Type 2 processes are *hypothetical thinking* and *cognitive decoupling*: that is, the ability to block out heuristic responses while simulating alternative responses. Furthermore, Evans and Stanovich (2013) distinguish several features that may not define these types, but that strongly correlate with them. According to them, typical correlates for Type 1 are: fast, high capacity, parallel, nonconscious, biased responses, contextualized, automatic, associative, experience-based decision-making and independent of cognitive ability. Type 2 correlates are slow, capacity-limited, serial, conscious, normative responses, abstract, controlled, rule-based, consequential decision-making and correlated with cognitive ability. Frankish (2010) states that there is much common ground to construct a composite dual-system picture based on features commonly ascribed to each system. He suggests the features listed in Table 1-1.

Table 1-1. Features of processes commonly ascribed to the two systems (adapted from Frankish, 2010).

Type 1 processing	Type 2 processing
Fast	Slow
Automatic	Controlled
Nonconscious or preconscious	Conscious
Low effort, high capacity	High effort, low capacity
Heuristic	Analytic
Associative	Rule-based

Despite the fact that different theorists distinguish different characteristics of both types, the distinctions that they make are qualitatively similar (Evans & Stanovich, 2013).

Another distinction can be made on the basis of the hierarchy of both types, and the order in which they may be engaged. According to Evans and Stanovich (2013), a rapid, autonomous process is assumed to yield default responses (Type 1), but sometimes it requires intervention and replacement by the distinctive higher-order reasoning processes (Type 2). The viewpoint that Type 1 and Type 2 processes do not work in parallel, but that the default Type 1 may be overridden by Type 2 is coined the 'default-interventionist' approach. The alternative approach is represented by 'parallel-competitive' models, in which the two processing types proceed in parallel and compete for behavioural control.
The proposed model of banknote authentication described in Chapter 2 of this thesis can be considered an example of a 'default-interventionist' approach, first described by Evans (2007). According to default-interventionist theories fast thinking (Type 1) generates intuitive default responses in which subsequent slow thinking processing (Type 2) may or may not serially intervene. The crux in the proposed model is that by default cash transactions are done on autopilot. Yet when something challenges our (unconscious) expectations, there may be an interrupt signal and conscious processing gets on line (Eagleman, 2015). Although humans may try to do as much as possible on autopilot, in some cases unexpected events may force Type 2 processing. Hence, by default, people accept counterfeit banknotes automatically, unless Type 2 kicks in because one is triggered by something unexpected, like unusual haptic feedback when touching the banknote.

1.3 Stimulus material (genuine and counterfeit euro banknotes)

In this section, I will elaborate on the characteristics of the banknotes, either genuine or counterfeit, and both the use and misuse of this stimulus material.

1.3.1 Genuine euro banknotes

Euro banknotes are the common currency of 341 million people across 19 countries: the euro area (European Union, 2021). The first series was introduced in 2002. The second, the Europa series, was gradually introduced starting from 2013 onwards until completion in 2019 (ECB, 2022b). The euro banknotes originally had seven different denominations: €5, €10, €20, €50, €100, €200 and €500. Recently, the €500 denominations was no longer issued anymore (as of 27 April 2019 (ECB, 2022b). Each denomination has its own distinctive colour as well as an image of an architectural style reminiscent of various periods in Europe's history. The facades of these buildings feature windows and doorways, symbolizing the European spirit of openness and cooperation. The bridges on the back symbolize communication among Europeans and between Europe and the rest of the world. The windows, doorways and bridges shown on the banknotes are stylized illustrations, not images of, or from, actual constructions.

The Eurosystem, just as all central banks around the world, incorporates various security features in its banknotes to assist users in identifying counterfeits. Among the users that are identified by the central banks are (1) the general public (including visually impaired people), (2) the retail sector, (3) the vending and banknote processing machine industry, (4) the banking sector and (5) the central banks themselves (Heinonen, 2015). The security features can be categorized at three levels, each intended for different usage. Security features at the first level can be authenticated using the human senses. Second-level security features can be authenticated with equipment (run-of-the-mill authentication devices used by retailers or more professional banknote sorting equipment used by cash management companies). Level 3 security features can be authenticated solely by central banks. This thesis limits itself to the security features that are intended for the general public (level 1).

These level 1 security features should be recognizable without any equipment. Examples are a watermark, a security thread, optically changing elements, foils and holograms, the feel of the banknote paper and the relief resulting from intaglio printing. All these features appeal to two of the five senses, sight and touch. Central banks typically issue information tools like leaflets and websites to inform the public about these features, because it is not clear from the banknotes themselves what these feature are, where they are located and what to do with them (de Heij, 2007). Figure 1-3 shows the main public features of the euro banknote, which can be perceived by the 'feel, look, tilt'-method recommended by the European Central Bank (ECB, 2016). Central banks generally put effort into educating people about these features by publishing relevant information on their websites, by providing euro information materials or training, exhibiting materials in central bank visitors centres and by launching campaigns at the start of the introduction of new series.

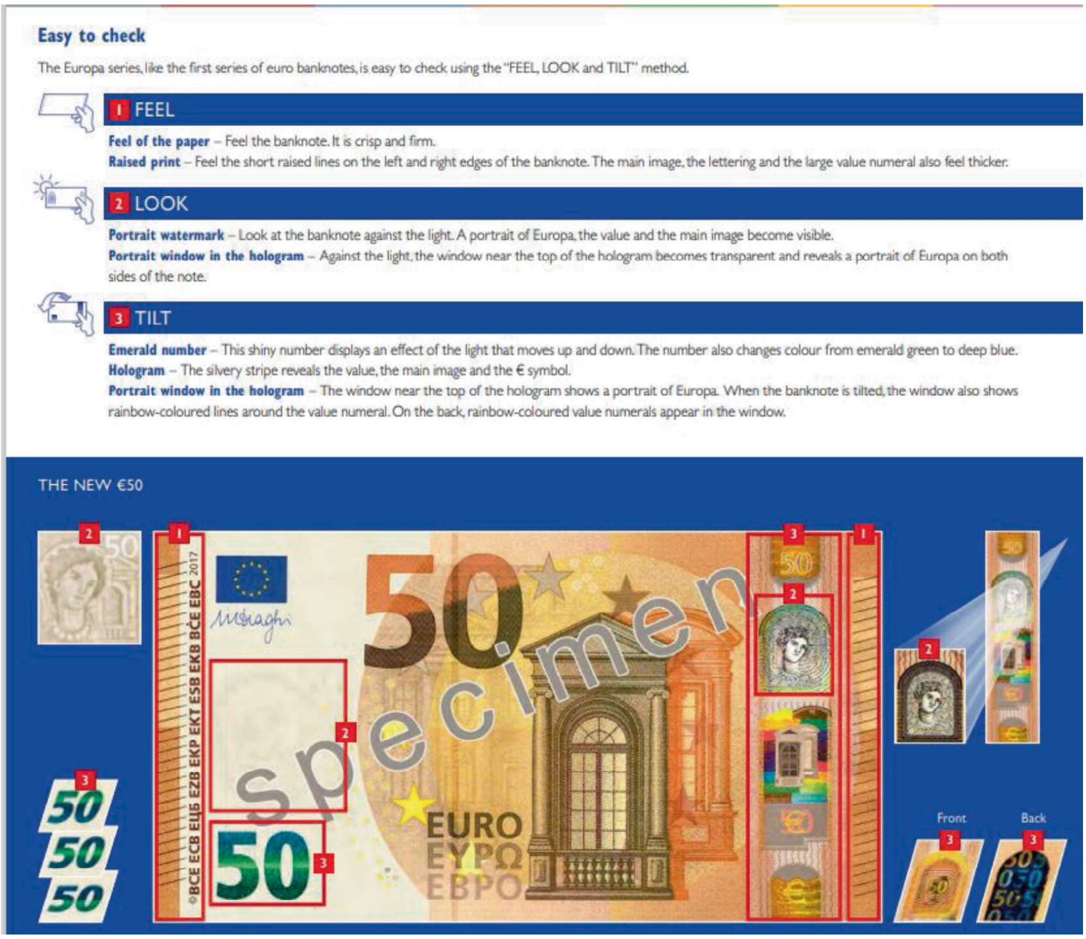

Figure 1-3 Public security features of EUR 50 note. Source: ECB Leaflet for the public.

1.3.2 Counterfeit euro banknotes and the counterfeiter

Relatively few counterfeit euro banknotes (around 700,000) were withdrawn from circulation in 2017 (ECB, 2018). This is a ratio of only 0.003% compared to well over 20 billion genuine banknotes in circulation, with a total value of more than EUR 1.1 trillion. During the pandemic, when the use of cash dropped, the ratio was even lower (0.001%) because of the historic low number of counterfeits (347,000) compared to the 28 billion genuine banknotes in circulation (ECB press release, 28 January 2022). Still, compared to other currencies, the global acceptance of the euro as a stable currency with low rates of inflation makes it an attractive currency for counterfeiters. The €20 and €50 denominations form two-thirds of all counterfeit euro banknotes (Table 1-2). The probable reasons for this are that the €20 and €50 banknotes are the most frequently used transaction denominations. These are also the most commonly dispensed denominations at ATMs. In addition, counterfeiters are aware of the fact that people will pay more attention to higher denominations. Lastly, lower denominations than €20 are not profitable enough for counterfeiting.

Table 1-2 Breakdown of all counterfeits removed from circulation by denomination in 2021 (Source: European Central Bank Press release 28-1-22).

Denomination	€ 5	€ 10	€ 20	€ 50	€ 100	€ 200	€ 500
Percentage breakdown	2.4%	15.7%	32.1%	33.8%	9.5%	5.5%	1.0%

According to de Heij (2017), counterfeiters settle for about half the maximum achievable mimicking quality of all public authenticity features. Since 2008, DNB has applied the 'Simple Method'. According to this method, a score of 0, 1 or 2 points is given in accordance with the quality of the feature reproduced, indicating that the feature is not imitated (0 points), obviously imitated (1 point) or is a deceptive imitation (2 points). The average score over the period 2008-2015 for all six security features combined was 5.9 out of 12 points. De Heij (2017) concluded that counterfeiters seem to focus on imitating the security features that people recall most often such as the watermark and portrait hologram. Due to the lack of focus on other security features, the 50% level of mimicking quality of counterfeits seems to be enough to fool people. According to a study by DNB, Europol and DSP-group in the Netherlands (2012), counterfeits are most commonly offered at restaurants/café/bars (30%) and supermarkets (20%). Those caught paying with counterfeits are younger than 25 years in most cases. 39% of the people trying to pass counterfeits are still in high school.

1.4 The users

As said, this thesis focuses on the authentication of banknotes when they are handed over in a cash transaction without the use of additional equipment. Authenticating without special equipment is mainly performed by the general public, but also in some cases by retailers. Typically, retailers handle banknotes with the aid of banknote authentication devices. However, in the Netherlands, one-fifth of all cash authentications at the point of sale is done with human senses only (DNB/Panteia, 2015).

Research has shown that people who are instructed about the public security features just before an authentication task are on average able to detect 96% of medium mimicking-quality counterfeits (Jonker et. al, 2006). However, the general public typically has not received any training or has forgotten the public information that the Eurosystem provided at the start of a series. Educating the general public in sophisticated but recognizable security features has proven to be unsuccessful (Schaede & Lohweg, 2006). People are generally not very receptive to information provided by central banks when there is no alarming situation at hand. This is why the average individual in the Netherlands can only recall about two security features off the top of their head, of which the watermark (69%) and the portrait hologram/silver foil (39%) are the best-known features (DNB/Panteia, 2021). Although it may seem reasonable that more than two-thirds of participants mention the watermark, only 3% of respondents know that the watermark depicts a person. There is very little recall of introduced features. For instance, the emerald numeral with optical variable ink (OVI: the numeral changes from green to blue when tilted) was introduced in 2013, but was mentioned by only 2% of respondents eight years later (DNB/Panteia, 2021). Some individuals of the general public identify other aspects of banknotes as security features. For example, around 7% of the general public think that authenticity can be checked by looking at the signature on the banknote (van der Horst, Eschelbach, Sieber & Miedema, 2016). However, the signature is not an official security feature as signatures on banknotes change with new presidents. So far the signatures of Duisenberg, Trichet, Draghi and Lagarde have appeared on euro banknotes.

Furthermore, even when people know about the existence of a security feature, they generally do not know how to check it. People are basically not aware of the "feel, look and tilt" method described on the websites of the ECB and national central banks (van der Horst, de Heij, Miedema & Van der Woude, 2017).

People hardly make an effort to check a banknote. Figure 1-4 shows that 59% of the Dutch public state that they never checked for authenticity in their lives unless it was required for work (DNB/Panteia, 2021). Those who checked banknotes in the past year (17%) did so only occasionally.

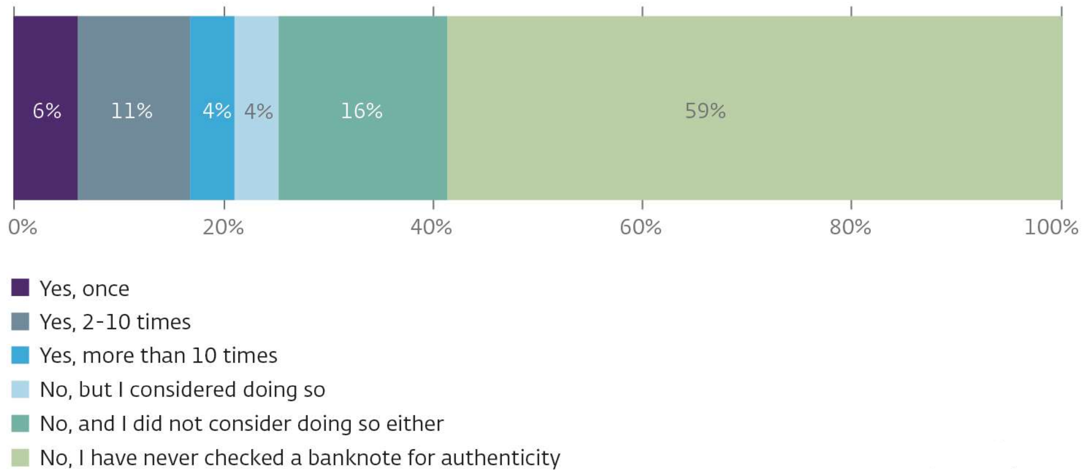

Figure 1-4. Percentage of participants that have checked a banknote for authenticity in the past year (i.e. for own personal use and not in the context of work). (n=1,003). Source DNB/Panteia 2021.

The minority of the Dutch population that did check a banknote in the past year indicated having done so mainly out of habit (19%), curiosity (17%), followed by a different feel of the paper (15%) and a potential suspicion of person who was handing it over (11%) (DNB/Panteia, 2021). Figure 1-5 gives an overview of the reasons provided for authenticating a banknote in the past year.

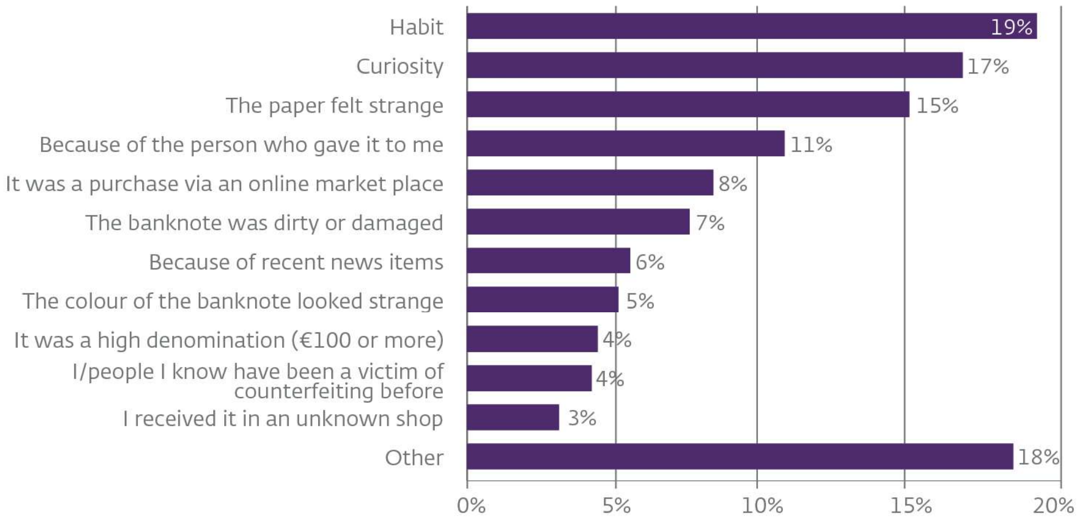

Figure 1-5. Reasons provided for checking a banknote in the past year (n=212). Source: DNB/Panteia, 2021.

Obviously, because they generally handle more banknotes per day than the general public, retailers are more prone to authenticate than consumers. In a non-published ECB cash handlers survey conducted by Ipsos European Public Affairs (2021), it was found that authenticity checks are very common (6 in 10 professional cash handlers check banknotes), with trained professional cash handlers doing so almost universally. Nevertheless, a substantial share (39%) of professional cash handlers do not conduct checks. Almost a quarter of them do not authenticate because they find it fairly/very difficult to perform such a task. The most commonly mentioned reasons among this subpopulation are that counterfeits look too much like genuine banknotes, there are too many security features to remember, it is hard to find the security features on the banknotes and they do not know how to check for authenticity.

Higher value banknotes are the most likely to be checked. The security thread, the portrait watermark, the feel of the paper and the portrait hologram are the most commonly mentioned features that professional cash handlers regularly check.

1.5 Thesis outline

On the basis of the discussion of Chapter 1, Chapter 2 presents a dual processing model for accepting or rejecting a counterfeit banknote. This model will map the phases of a cash transaction, specifying the relevant factors that can be the cause for a switch from automatic, intuitive processing to a more deliberative mode. A distinction is made between factors such as the attitude of the receiver, the situation of the transaction and the banknote.

Chapters 3, 4 and 5 comprise some supporting empirical evidence for parts of the dual processing model. Chapter 3 deals with the research question of whether the quality of banknotes in circulation (genuine or otherwise) affects counterfeit detection. This refers to one of the situational factors that are part of the model. Chapter 4 refers to the respective roles of vision and touch when authenticating a banknote that is presented either for a very short or a long time. Chapter 5 shows that 1) adding salient design elements to a banknote, and 2) manipulating trust both may improve authentication. Furthermore, the chapter provides a proof-of-concept as to how banknote designs may be improved on the basis of our understanding of the cognitive processes involved.

Chapter 6 presents the overall conclusions regarding the factors affecting the probability of detecting a counterfeit banknote. It also provides suggestions for the characteristics of intuitive security features, meant to contribute to confidence and easy authentication.

2

A dual processing model for accepting or rejecting a counterfeit (MARC)

This chapter describes a model involving two different kinds of cognitive processes, both leading to a judgement and decision to either accept or reject a counterfeit. It specifies four different phases of a cash transaction. First there is a brief description of the main characteristics of the model, and then there is a discussion regarding the two types of processing in relation to the cash transaction, followed by a description of the factors that might play trigger a switch from automatic Type 1 processing to a more deliberate mode of Type 2 processing.

2.1 Main characteristics model

As most people indicate that they have never checked banknotes for authenticity and typically do not know how to check a banknote, the chances are high that counterfeits remain unnoticed, especially because most cash transaction are done by means of automatic (Type 1) processing. In most situations, people have the tendency to accept a banknote without much, if any, conscious deliberations. However, particular factors may induce a Type 2, more conscious and deliberate process of checking the authenticity. In turn this may increase the likelihood that a counterfeit will be detected. These factors can be categorized into three different types: the attitude of the receiver, the situation in which the transaction takes place and the characteristics of a banknote. Figure 2-1 presents a model that we labelled as the dual processing Model for Accepting or Rejecting a Counterfeit (MARC) in which these different aspects may play a role.

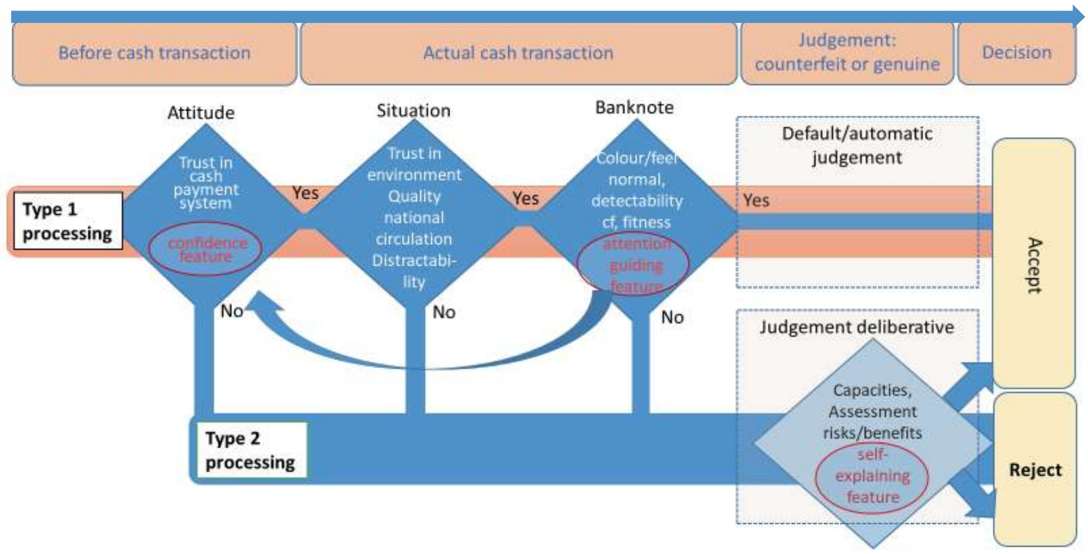

Figure 2-1. A dual processing model for accepting or rejecting a counterfeit (MARC). MARC describes four phases of a cash transaction leading to acceptance or rejection of a counterfeit banknote. During each phase, people use Type 1 automatic processing unless their attitude, the situation, or the characteristics of banknote gives reasons to switch to Type 2 processing . A deliberative judgement and decision requires capacity, knowledge and a weighing of benefits and risks. The model provides suggestions at certain points (in red circles) for important attributes of security features.

The model consists of four phases, mentioned at the top of the model in Figure 2-1. The first phase is before the actual cash transaction takes place. In this phase, people's general attitude towards the trustworthiness of banknotes is relevant. Here, attitude is defined as a general and lasting positive or negative viewpoint regarding the cash payment system. Attitudes are shaped either by personal experience, prior observations, influences of others or influences of the media. As described in the Introduction, those who are confident in the cash system typically start a transaction according to Type 1 processing. However, it is likely that if an individual has been tricked before, that person will be much more careful and more likely to engage in Type 2 processing.

The second phase entails the actual receipt of the banknote. This may be an everyday situation such as a transaction at the local supermarket, or in a less familiar context such as during the incidental purchase of a second-hand product. The banknote that is handled may have properties that might induce more careful and deliberate Type 2 processing.

During the third phase, the person will arrive at a judgement by making some implicit or explicit estimation about the authenticity of the banknote. If by this time the Type 1 processing has not been interrupted, the banknote will be automatically, and implicitly, judged as genuine and accepted. However, should the individual switch to Type 2 processing, the judgement will depend on their authentication skills, knowledge of the security features and the extent of intuitiveness of the security features.

In the fourth phase, the receiver decides either to accept or reject the banknote. It is important to realize that the final decision can be made regardless of one's own better judgement, as rejecting a banknote that is assumed to be counterfeit may lead to negative (social) consequences. Some retailers, for instance, accept a presumably counterfeit banknote in order not to embarrass their customers or because they do not want to lose time dealing with the counterfeited banknote. Receivers might be afraid of the consequences if they would (falsify) accuse the payer of counterfeiting. On the other hand, counterfeits are not reimbursed by central banks, which makes the cost of accepting a counterfeit banknote equivalent to its value. People will probably (implicitly) calculate the risk. People will be more prone to act like nothing serious has happened when they receive a small amount (e.g. a €5 banknote) than when they receive a high denomination (e.g. a €200 banknote). The loss is more bearable in the first case (DNB/Panteia, 2021).

2.1.1 Automatic processing, Type 1

Most cash transactions are automatic, fast, effortless, and unconscious, which correlates to the default Type 1 processing. This is because banknotes are still omnipresent and used basically every day. In 2019, around 73% of all payments in the Eurozone at points-of-sale (P.O.S.), i.e. the place where a transaction is completed, like a supermarket or a petrol station, were made in cash (European Central Bank, 2021). However, even in countries where the use of cash is diminishing and where cash is no longer the dominant payment method, like the Netherlands, cash usage at POS is nonetheless substantial. Approximately one in five transactions in the Netherlands took place in cash in 2020. This represents a sharp decline from 32% in 2019, and can mainly be ascribed to the COVID-19 pandemic (DNB, 2021).

Everyday transactions take place in a more or less automatic fashion without much, if any, conscious control. In a non-peer-reviewed fMRI study by Neurensics commissioned by DNB (van der Horst & Matthijsen, 2013), it was shown that paying with cash activates automatic behaviour. In order to be able to investigate whether debit card or cash payments lead to automatic motor activity, it had to be determined for each participant which brain patterns were associated with automatic motor behaviour. To that end, each of the 35 participants had to perform two simple motor tasks like pressing four buttons in a particular fixed order before they entered the fMRI scanner. These tasks had to be performed repeatedly until the participant could perform them blindly. The brain activity during this automatic task was then compared to new tasks. This allowed to map the areas in the participants' brains that were activated by automatic behaviour and correlate them with the brain activity pattern for the relevant task in the test. In the test, brain activity was triggered by two events during the fMRI scan: 1. watching a film of somebody paying in cash or by card, and 2. the participants having to pay themselves either in cash or by card by pushing a button in a virtual shop. Stronger automatic behavioural responses were triggered when the participants watched or made cash payments than when they watched or made card payments. Both debit cards and cash activated automatic behaviour, but stronger automatic behavioural responses were triggered when the participants watched or made cash payments than when they watched or made card payments. However, the study was performed in 2012, when still 59% of all purchases were paid for in cash. Nowadays only one in five transactions is paid for in cash and four by debit card. It is possible that if the same study would be repeated today, the balance in automatic responses would shift more towards digital payments.

If the factors mentioned in this chapter do not make a payee suspicious during Type 1 processing, then the payee will continue to handle a given cash transaction automatically, just like tying shoelaces in the morning. The implicit, subconscious decision will be to accept the banknote, even though it might be counterfeit.

2.1.2 Controlled processing, Type 2

In some cases, automatic behaviour during a payment transaction may be interrupted, which will lead to a more deliberative Type 2 mode of processing to establish whether the banknote is genuine. As explained, there are several factors that may override the Type 1 processing and trigger people to attend more closely to the cash transaction. These factors may be related to the receiver of the banknote, the situation and/or the characteristics of banknote, and are described below. Processing a cash transaction in a controlled way requires that people reflect on the possibility that the banknote in question might be fake. If the payee has insufficient knowledge then he/she will actively look for clues. This might be through touching and feeling the paper, touching its structure or searching for clues that may indicate that something is wrong. Obviously, the extent to which someone is able to successfully authenticate depends on knowledge, expertise and capacities of the individual (see Section 2.1.12).

2.2 Factors triggering Type 2 processing

The following describes the circumstances under which Type 2 processing might be initiated.

2.2.1 Attitude towards cash

Before a cash transaction takes place, it depends on the trust people have in the cash payment system whether they will start the transaction in the default mode (Type 1) or whether they will immediately engage in a more deliberative authentication process (Type 2). In general, people have confidence in the authenticity of banknotes coming from an ATM or a retailer. On a scale from 1 to 10, the average confidence in the authenticity of a banknote coming from a retailer is 7.5 and from an ATM 8.9 (DNB/Panteia, 2021). Furthermore, people assume that central banks take measures to protect the authenticity of the banknotes. It is generally believed that security features on banknotes are present to ensure that it is difficult for counterfeiters to counterfeit the banknote. People do not think that the security feature are necessarily relevant to them (van der Horst et al., 2017). Overall, since 2005 - when this was first measured - the public has shown a high and increasing confidence in the authenticity of banknotes (Figure 2-2).

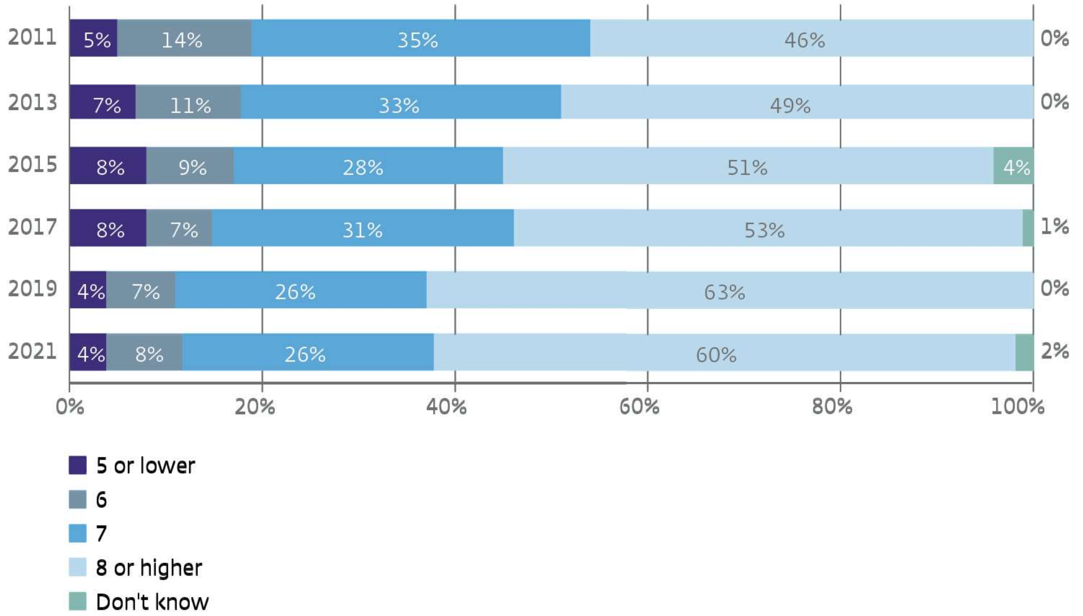

Figure 2-2. Scores for participants' trust in the authenticity of euro banknotes, on a scale from 1-10 (n=1,003). Source: DNB/Panteia 2021.

The fact that the public generally trusts banknotes received at ATMs and from retailers is the most frequent reason for not checking its authenticity (DNB/Panteia, 2021). People who have checked a banknote twice or more often during the past year have significantly less confidence in the authenticity of banknotes compared to those who have never checked for authenticity in the past year (DNB/Panteia, 2021). Trust in authenticity is to be expected as banknotes that are dispensed at ATMs are checked for fitness and genuineness according to Eurozone rules and regulations (ECB Decision 2010/14). Furthermore, according to de Heij (2017) people witness retailers passing banknotes through devices, which encourages their trust. Lastly, people are confident that central banks take thorough precautions to protect their banknotes. A focus group of Dutch participants state that especially the security features on banknotes that give the suggestions that they are hard to imitate add to the confidence in the system (van der Horst et al., 2017). Confidence is also bolstered by the fact that the likelihood of receiving a counterfeit in the Eurozone is extremely low (also see Section 1.3.2). Research has shown that people often treat highly unlikely events as basically impossible (Kahneman & Tversky, 1979).

It should be noted that particular features can contribute to confidence in the authenticity of banknotes. Features that give the suggestion of being difficult to counterfeit, even if this is not the case in reality, contribute to the confidence that people have in the authenticity of the banknote (van der Horst et al., 2017). It could be argued that this is one of the desired criteria of a good security feature. However, whereas the introduction of a security feature that appears complex might boost confidence in the system, it will not necessarily make the authentication task any easier.

In addition, people have a certain sense of security, which is likely to be affected by the ease with which they can recall counterfeiting incidents. According to the availability heuristic (Tversky & Kahneman, 1973), when these incidents are easily recalled because of for example a large media coverage or their own experience, people expect that counterfeiting is more likely to occur. Kosse (2013) showed, for instance, that newspaper publications about skimming have a negative effect on debit card usage. The size of the effects, however, fluctuates over time, with consumers' reactions being stronger in periods immediately following media coverage. The availability heuristic can substantially and unconsciously influence the judgement of real risks. Dutch respondents who have received a counterfeit banknote in the past five years tend to report significantly more often that they have carried out authenticity checks. They mention significantly less often that they have never checked a banknote, nor considered it (Visser & Dijkers, 2013).

2.2.2 Trust in the environment

As depicted in Figure 2-2, Phase 2 entails the actual cash transaction, which is assumed to depend on the situation (factors within the immediate context affecting trust) and the banknote.

Trust in the environment is an important factor when handling a cash transaction. DNB commissioned the Vrije Universiteit of Amsterdam to investigate the manipulability of payment method choice in an online virtual reality study (van der Horst & Matthijsen, 2013). The study involved an online game that a representative panel of nearly 1,300 participants was asked to play, simulating an everyday life transaction. One of the variables was the environment, which was used to manipulate the participants' sense of physical safety. In order to reach their destination, some of the participants were told that they would need to walk through a dark area. Other participants did not receive such a warning. It was shown that taking a walk in the dark reduced the inclination to carry cash, regardless of whether this was to a restaurant or a supermarket., In general, one can imagine that the environment in which a transaction takes place affects the need to check the authenticity of a bank note received. In the Netherlands people spend an average of 45 minutes per week in a supermarket, distributed over either onceweekly shopping, or daily, quick visits (Slob, 2020). When receiving a banknote in such familiar surroundings there is less reason to doubt the authenticity, than for instance when receiving change from a street seller in a rough environment. In general, in unusual situations, it is expected that people may be more concerned about whether they can trust the banknotes they receive.

2.2.3 Banknote circulation quality in a country

As will be discussed in Section 2.2.3 the ECB provides a framework for ensuring a certain level of quality or fitness of banknotes in circulation. One of the underlying ideas is the notion that a high quality of the (genuine) banknotes in circulation helps the public to detect counterfeits. This aspect is discussed in detail in Chapter 3 in which it is shown that indeed the quality of banknotes affects the chances of counterfeit detection. In a situation of clean circulation, participants identify more counterfeits, yet they also have a stronger tendency to declare the cleaner genuine banknotes as counterfeit.

2.2.4 Time pressure, distractibility

When people experience time pressure to handle a cash transaction quickly (e.g., a long line at the supermarket), the likelihood of people taking time to deliberately check a banknote decreases. Moreover, time pressure also has a detrimental impact on perception in a more general sense. This was shown, for instance, in a study by Rieger, Heilmann and Manzey (2021) involving a simulated luggage screening task. In this study participants were either assigned to a low time pressure condition (10s per trial) or a high time pressure condition (5s per trial). Better detection performance was obtained with low time pressure and participants had a greater tendency to overlook target items when under greater time pressure.

When executing a particular task, people store information regarding the task temporarily in working memory (van der Stigchel, 2020). However, when irrelevant information enters working memory, for instance noise in a crowded bar, attention may get distracted and less attention may be devoted to the original task. When someone is about to receive a banknote from a supermarket cashier, but is suddenly distracted by shouting at another till, authentication performance is likely to decline or even may cease to occur. When people are distracted because they are conducting another task research has shown that they may fail to see objects or stimuli that are unexpected even when they are quite salient. This phenomenon is known as ‘inattentional blindness’ or ‘perceptual blindness’ (Lavie & Dalton, 2014), as described in Section 1.2.3. An example of this phenomenon comes from a study by Strayer, Cooper and Drews (2004). They examined the effects of hands-free cell phone conversations on driving in a simulator. It was found that even when participants looked directly at objects in the driving environment (e.g., cars, trucks, pedestrians, signs, billboards, etc.), they were less likely to create a lasting memory of those objects when they were talking on the phone. It was suggested that even when participants direct their gaze to objects in the driving environment, they may not "see" them because their attention is focused elsewhere.

Anecdotal evidence that this phenomenon also occurs in the case of cash transactions can be derived from a demo that was conducted during a DNB cash research seminar in 2018. During the demo, about 40 participants were asked to count the number of yellow stars on the banknote that is shown in Figure 2-3. After asking the participants (who were all banknote experts) if they had noticed anything unusual, nobody mentioned the gorilla in the window. After revealing where it was, everybody was very surprised that they had missed such an obvious image.

Figure 2-3. Image of a €20 banknote where a gorilla is 'photoshopped' in the hologram window to demonstrate inattentional blindness to experts at a DNB cash research seminar 2018: the invisible gorilla strikes again! (PowerPoint slide made by van der Horst (2018).

In sum, if the environment is as familiar, and if people feel time pressure, or are distracted and the perceptual workload is high, there is no inclination to abandon the Type 1 processing mode. On the other hand, if the environment is not trustworthy, there is no time pressure and people are not distracted, they are likely to be more cautious and Type 1 will be overridden by Type 2 processing.

2.2.5 The detectability of the counterfeit

If the counterfeit is of high quality, people might not be triggered to take a closer look. If however the imitated features are poor, then it is relatively easy to establish that something is wrong, increasing the likelihood of taking a closer look. The material or substrate of counterfeit banknotes that deviates from genuine banknotes may act as a trigger (Chapter 3). Counterfeits made with laser printers often feel different (waxlike). Inkjet printers however have no perceivable impact on the substrate, so when the counterfeit is printed on cotton-based paper, the deceptive nature of the substrate stays intact. Another trigger is the colour/print quality (Chapter 3). Suppose an individual is triggered by either the feel or the print quality, then they might establish whether the note is genuine. Extensive experience with banknotes may result in the a vivid representation of these banknote in mind (Pinker, 1997). If a banknote clearly looks different from the stored mental image, Type 1 processing will be stopped and people may engage in a more deliberate inspection of the banknote. If a genuine banknote contains features that 'pop out' from the scene, the eye will be drawn automatically to the location of the pop-out feature. In Chapter 5 is investigated how salient features can improve banknote authentication. Introducing salient features on a banknote may be useful. When saliency is missing, or badly mimicked, the receiver will have a feeling that "there is something wrong" and will be triggered to investigate the banknote further. When a security feature contains salient elements, and when it is mimicked rather well, then saliency does its job, guiding people towards this feature and helping them to distinguish genuine from counterfeit.

2.2.6 Banknote fitness

People expect banknotes to be in adequate condition. The ECB has established rules for the required quality or fitness level of a banknote (EB Decision 2010/14). National central banks must sort the returned banknotes according to these rules. DNB asked 1,003 Dutch respondents the question 'How do you feel about the quality of a banknote thinking of dirt, wrinkles, tears, writing, tape, etcetera?' (DNB/Panteia, 2021). Regarding the €50 banknote, the most counterfeited denomination, most of the respondents (87%) considered them very or fairly presentable. If someone encounters a banknote that is very unfit, for instance very dirty, suspicion was raised. 7% of participants mentioned this as a reason for a deliberate check. (DNB/Panteia, 2021).

2.2.7 Experience, training

As discussed before, people are generally uneducated when it comes to detecting counterfeits. Retailers perform better on banknote authentication tasks (without equipment) because they sometimes have had training, and because they have more experience with banknotes than the general public. Eurozone citizens conduct on average 1.6 point-of-sale and person-to-person transactions per day (European Central Bank, 2021), but retailers handle considerably more banknotes. According to a survey conducted on behalf of DNB (TNS NIPO, 2004), retailers in the Eurozone handle on average 120 banknotes per day. The more experienced people are, the higher the likelihood that they will notice that something is wrong. A lack of knowledge about the existence and function of security features and the lack of any training may be (partly) solved by introducing security features that are self-explanatory, and intuitively help the authentication process.

2.2.8 The visual and haptic abilities

People obviously differ in their capacities to notice when something deviates from the expected. Capacity differences exist not only at an individual level, but also between specific groups of people. Many cognitive functions along with perception capacities deteriorate with age (Lavie & Dalton, 2014). This is especially important as elderly people rely on cash more often than young people (ECB SPACE, 2021).

2.2.9 Assessment of risks and benefits

After the automatic or deliberative judgement to establish whether the banknote is a counterfeit, a decision about whether the banknote will be accepted or rejected must follow. This decision will be based on that judgement, but can be based on other considerations as well. When Type 1 behaviour is not overridden, then the decision is in accordance with the judgement. When the banknote is deliberatively authenticated, and the recipient comes to the conclusion that it is counterfeit, the decision to accept or reject might be based on an assessment of risks and benefits. Obviously, the benefit of rejection is the prevention of loss of money. Also, if the payer is perceived by the recipient as potentially dangerous, then the recipient might decide to accept the potential counterfeit and bear the loss. The recipient could even be afraid that an embarrassing situation might arise if their judgement turns out to be wrong.

In this chapter, we have presented a model containing the different elements that lead either to acceptance or rejection of a counterfeit, either via default or deliberate processing. In doing so, we reflected on properties of the payee, the situation and the properties of the banknote. The following three chapters present empirical evidence for the role of these factors in banknote authentication. More specifically, the evidence will focus on the importance of trust in the authenticity of euro notes, the influence of salience in design, the influence of the quality of the national banknote circulation in which counterfeits occur and the influence of expertise.

3

Does banknote quality affect counterfeit detection? Experimental evidence from Germany and the Netherlands[1]

[1]This chapter corresponds to: van der Horst, F., Eschelbach, M., Sieber, S., & Miedema, J. (2017). Does Banknote Quality Affect Counterfeit Detection? Experimental Evidence from Germany and the Netherlands. Jahrbücher für Nationalökonomie und Statistik, 237(6), 469-497.

Counterfeit prevention is a major concern for central banks. In search of effective policy measures, it is often claimed that a clean banknote circulation helps the general public to more easily detect counterfeits. To examine this claim, we conducted an experimental study with 250 consumers and 261 cashiers in the Netherlands and Germany. Participants received 200 banknotes with either a high or a low average soil level. The banknote test sets contained 20 counterfeits to be detected by the participants. For the regression analysis we applied approaches used in the area of psychophysical science (signal detection theory). Our candidates identified more counterfeits when sorting clean banknotes. However, our analysis also showed that the cleanliness of banknotes does not actually help the person checking the banknote to more easily distinguish a counterfeit banknote from a genuine note. In fact, new and clean banknotes raised suspicion: they were more often declared as counterfeits – correctly or not. We discuss the implication of our results for central banks' banknote policies.

Keywords: banknotes, counterfeits, banknote quality, signal detection theory

JEL-classification: E40, E41, E50, E58

3.1 Introduction

Counterfeit prevention is high on the political agenda of every central bank. For the individual, inadvertently accepting counterfeit banknotes or coins can lead to a considerable financial loss, as counterfeits are not reimbursed. At the national level, elevated counterfeiting rates can jeopardise confidence in a currency. In search of effective policy measures, it is often claimed that a high quality of the banknotes in circulation - i.e. clean and undamaged banknotes - helps the public to more easily detect counterfeits (ECB, 2010). To assess this claim, we conducted an experimental study with 250 consumers and 261 cashiers in the Netherlands and Germany. During the experiments, we tested whether candidates were better at identifying counterfeit banknotes if they were hidden in stacks of clean banknotes or in stacks of soiled banknotes. The counterfeit banknotes themselves were drawn from actual circulation and exhibited an average soil level. The study was jointly carried out by De Nederlandsche Bank (DNB) and the Deutsche Bundesbank (DBB), with the help of the VU University Amsterdam.

The national central banks (NCBs) of the Eurosystem aim to ensure a consistently high quality of the euro banknotes in circulation. That is to say, banknotes must not be soiled, creased, limp or torn. In particular, banknotes must be clean enough so that they are acceptable to consumers and retailers as a payment instrument and can be used in banknote accepting devices, such as automated teller machines and vending machines. Furthermore, a clean banknote circulation is intended to inspire confidence in the euro as a currency in general. To this end, the national central banks of the Eurosystem have agreed upon minimum quality standards for banknote sorting. In practice, NCBs differ in terms of their sorting polices, which is one of the reasons why the quality of circulation differs between the various euro area countries. Some NCBs increase the minimum requirements for the cleanliness of banknotes by adding a 'counterfeiting factor'. Those in favour of high sorting standards argue that counterfeits are easier to detect in a clean circulation as security features are more clearly visible.[2] Those who argue against it claim that replacing more soiled banknotes with new ones raises the costs for central banks, while the effectiveness of the measure is still uncertain.

Scientific research on factors that can facilitate the detection of counterfeits by the general public is very scarce. The most comprehensive analysis is perhaps that of Jonker et al. (2006), who conducted an economic experiment with 164 cashiers and 40 consumers. However, the authors did not take the cleanliness of banknotes into account in their study. The main research question is whether the DNB training materials and technical aids, such as UV lights and IR cameras, are helpful in facilitating the detection of counterfeits. Candidates were asked to check a set of 220 euro banknotes and to sort out any counterfeits. The use of learning materials substantially

[2] This argument is also implicitly put forward in ECB Decision 2010/14: "To (…) enable a proper detection of counterfeits, euro banknotes in circulation must be maintained in good condition to ensure that they can be easily and reliably checked for genuineness, and therefore, euro banknotes must be checked for fitness."

improved the detection rate of consumers, while it had no effect on the performance of cashiers. Technical identification aids, by contrast, did not improve detection rates.

To the best of our knowledge, the only published study that also incorporates the cleanliness of banknotes as an explanatory factor is that of Klein et al. (2004). Commissioned by the Bank of Canada, the study focuses on the Canadian dollar. During the experimental tests, 158 consumers and cashiers were asked to examine a series of banknotes for a period of just a few seconds each. The banknotes comprised both genuine and counterfeit banknotes and varied in terms of cleanliness. In the empirical analysis, the authors look at both the quality of the individual note and the quality of the surrounding notes. For individual notes, they find that counterfeits are best detected when they are clean. However, the quality of the surrounding notes has no impact on counterfeit detection.

Our contribution to the literature is twofold. First, we study the relationship between banknote cleanliness and counterfeit detection in the case of the euro currency. As Canadian dollar and euro banknotes differ in terms of their design, material and security features, the results of Klein et al. (2004) do not necessarily apply to euro banknotes. With more than 18 billion notes in circulation, the euro banknote is one of the most widely used paper currencies in the world. Owing to sophisticated printing technology and high security standards, counterfeiting rates in the euro area are low compared to other currency areas (ECB, 2015). However, there are regional differences. For countries with higher rates, it might be interesting to find out whether raising the sorting standards of banknotes would be an effective counterfeit prevention measure.

Second, we are not only interested in whether banknote cleanliness affects counterfeit detection rates but also in how it achieves this. Security features of clean banknotes might be easier to recognise. This should enhance the testees' ability to distinguish between genuine and counterfeit banknotes and should enable them to sort more accurately. However, the level of cleanliness might also determine how sceptically users view their banknotes. Worn banknotes have already been used and checked by many people and might inspire more confidence than new ones. Besides, counterfeits are known to be rather clean, as counterfeiters probably do not deliberately soil their products.[3] If the participants in our tests are very sceptical towards clean banknotes, they will classify a relatively large number of them as being counterfeits. As a result, they will detect most of the counterfeits (hits) but also incorrectly classify many genuine notes (false alarms). In real life, such behaviour increases the public cost of banknote checking: people are inclined to check banknotes in greater detail, but in vain. If people are in fact more sceptical towards new banknotes, higher sorting standards would increase counterfeit detection rates, but would also lead to more meticulous authenticity checks. In this case, conclusions for a central bank's counterfeiting policy must be drawn more carefully.

[3] This assumption is partly based on the experience of central banks' counterfeiting experts and partly on the fact that the soil level of detected counterfeits is similar throughout the euro area, even though the average quality of banknotes in circulation varies.

In order to distinguish between sorting accuracy and suspicion among our testees, we rely on two concepts from signal detection theory: sensitivity and bias (Stanislaw & Todorov, 1999). In our context, sensitivity refers to how easy or difficult it is to distinguish between counterfeit and genuine notes. Bias, on the other hand, is the extent to which a candidate is inclined to call a banknote a counterfeit. These measures have been applied in psychophysical science for decades but are hardly known within the sphere of economic research. Yet they could provide new perspectives for the analysis of economic experiments as well. In our study, they efficiently combine information on both hits and false alarms and allow for a more profound analysis of the testees' performance.

Conducting a regression analysis, we find that candidates detect significantly more counterfeits when their test sets are clean (higher detection rate). Repeating the regression with a sensitivity measure as an outcome variable, we find that a clean test set did not specifically help testees to distinguish between genuine and counterfeit banknotes. In fact, the testees simply became more careful and sorted out more banknotes as being counterfeits (stronger bias).

The structure of this paper is as follows. Section 2 describes the experimental setting and the data collection. Section 3 presents the strategy of our empirical analysis. In Section 4 we describe our sample and report summary statistics before presenting our results in Section 5. Finally, Section 6 discusses the implications of our results for central banks' counterfeiting policy and sorting standards.

3.2 The experiment

3.2.1 Recruitment of participants

The target group in our study consisted of cashiers and consumers from Germany and the Netherlands. The field work was conducted between June 2014 and August 2015 and took place in the areas of Frankfurt and Amsterdam. In order to obtain a representative sample of consumers, we personally invited passerby in various locations, such as at city halls, open days at both NCBs, visitor centres, shopping precincts, community centres, various courses and public events, etc. Of the participating cashiers, the majority worked on the checkouts of large supermarkets, but some of them were shopkeepers in high streets. We explained to all participants that the tests were part of a scientific study on counterfeit detection conducted by the Dutch and the German central banks. We made it clear that participation was voluntary and that the results would be treated anonymously. Participating cashiers were assured that their individual results and the results of their store would not be passed on to the management.

Participants did not receive any monetary remuneration due to budgetary constraints. However, as counterfeits are an interesting topic, most of the candidates were happy to participate anyway. After finishing the test, they were asked to choose a small gift from a give-away collection, consisting of USB sticks, ballpoint pens or similar. We also offered to provide the participants with counterfeit training after the test to help them to more easily and reliably check the security features of euro banknotes and we also handed out information material.

3.2.2 Test sets

The participants' task during the tests was to sort a set of 200 banknotes. Altogether, we created eight sets of banknotes with equal characteristics, except for the level of cleanliness. All sets consisted of 180 genuine notes and 20 counterfeits. Both the DBB and the DNB were supplied with two sets of high quality and two sets of low quality banknotes.

We restricted the total number of banknotes in each set to 200 in order to avoid tiredness and boredom among participants. When determining the ratio between genuine notes and counterfeits we had to consider two opposing aspects: the probability of encountering a counterfeit in real life is very low which calls for a very low percentage of counterfeits in the test sets.[4] However, there are several classes of counterfeits that might all be perceived differently by the participants. In order to have a representative sample of counterfeits, a reasonably large number of fake banknotes was required. In the end, we decided on a share of 10% counterfeits (20 per stack of 200) as a compromise. Each test set consisted of equal numbers of EUR 20 and EUR 50 notes – both genuine and counterfeit. These denominations were chosen because – according to an ECB press release issued on 17 July 2015 – these denominations account for 86% of all counterfeits found in circulation in the Eurosystem.

All the counterfeit notes we used in the test sets are frequently found in the Eurosystem, and they were retrieved from actual circulation. They varied in terms of professionalism, but overall, they were quite deceptive. Furthermore, all of the selected counterfeit notes were, at that time, part of the Eurosystem test set used for assessing banknote handling machines and therefore represent the majority of counterfeits in circulation. We aimed to have an equal average soil level of the counterfeit notes in both the clean and the less clean sets. This is because we assumed that counterfeiters do not deliberately deteriorate their products to mimic the quality of banknotes in circulation. This assumption is partly based on the experience of central banks' counterfeiting experts and partly on the fact that the soil level of detected counterfeits is similar throughout the euro area, even though the average quality of banknotes in circulation varies. The soil level of the counterfeits was chosen so that they were not obviously different from genuine clean or less clean notes.

Counterfeits and genuine notes were randomly mixed in each test set so that the order of the banknotes would be different across the sets. After that, the banknotes of each

[4] Some 353,000 counterfeit euro banknotes were withdrawn from circulation in the Eurosystem in the second half of 2016. This number is very low compared with the 19 billion genuine banknotes in circulation (ECB, 2015).

test set were numbered (1-200) so that their order within the sets would remain unchanged during the tests.

3.2.3 Soil distribution

According to the general public, central banks do a good job of keeping the quality of the banknotes in circulation at a high level. For the euro area, the results of the ECB's online survey on the quality of euro banknotes in circulation (ECB, 2015) show that citizens consider the physical condition of the EUR 50 notes in circulation to be very high: 69% consider them to be in a good or excellent condition, and 20% believe they are in an acceptable condition.[5]

To establish a meaningful difference between the clean and the less clean sets, we looked at a Eurosystem internal quality survey from 2013. This survey measures the quality of the banknotes in circulation per country (sample size: 20,000), expressed in a scale of soil levels from 0 to 100. Typically, the distribution of the soil level is skewed: there are a large number of relatively clean notes, with a small number of dirty ones. *Figure 3-1* shows the actual difference between a country with a relatively clean circulation and a country with a less clean circulation.

[5] Several studies show that both the Dutch and the German public are even more satisfied with the present banknote quality than the average European citizen. According to a representative survey of the Dutch population, 83% of Dutch people state that euro banknotes in general are fairly clean or very clean. With regard to the EUR 50 banknote, as many as 88% of respondents are of this opinion (Randsdorp & Zondervan, 2015, p 13). A representative survey of the German population (Deutsche Bundesbank, 2015) draws a similar picture. 87% of German respondents state that they are satisfied or fairly satisfied with the quality of euro banknotes (e.g. their cleanliness and intactness). The same study also finds that the majority of the German population (58%) would not agree to a reduction in banknote quality, even if this were to reduce the cost to the public.

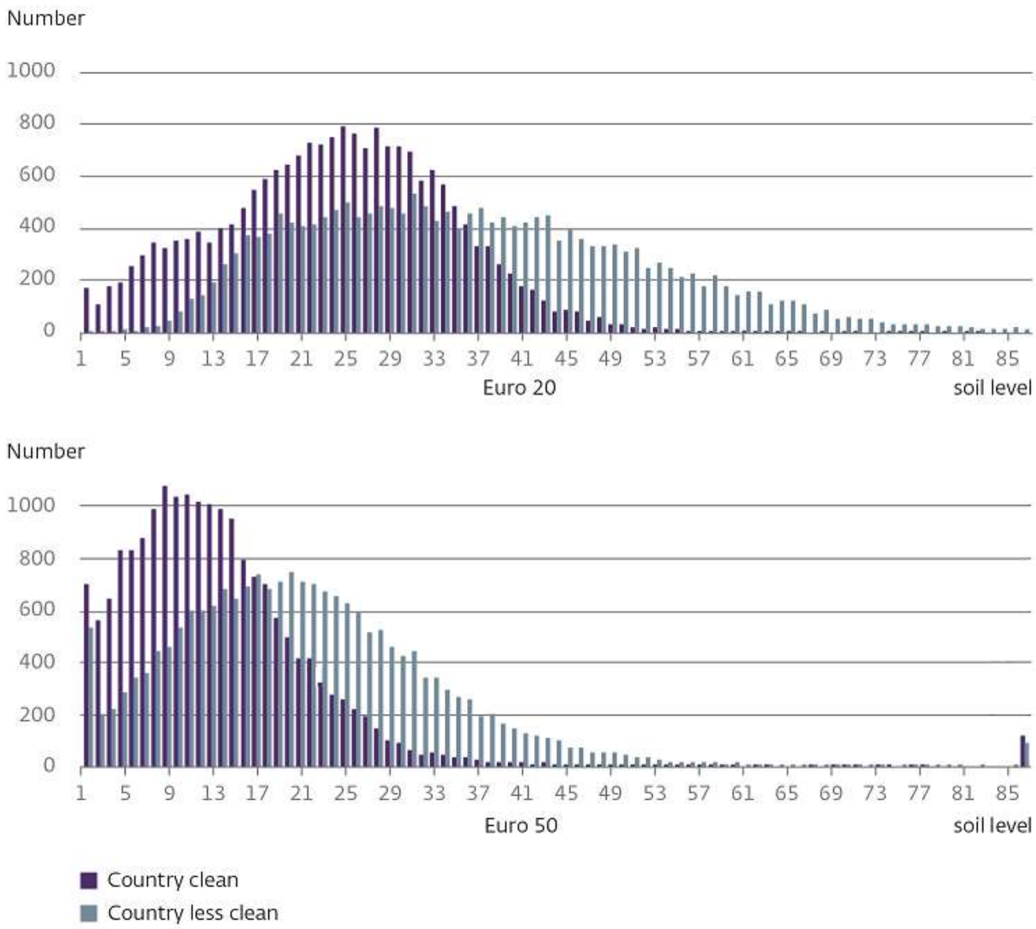

Figure 3-1: Distribution of soil levels of EUR 20 and EUR 50 banknotes in two countries.

To prepare the test sets, we considered the difference between a country C with a relatively clean circulation and a country LC with a relatively less clean circulation as a basis for the difference between the clean and less clean sets. In practice, the clean test set was based on the real-life average of the distributions of EUR 20 and EUR 50 banknotes in country C, whereas the less clean test set was based on the distribution of the EUR 20 note in country LC, which is the more soiled denomination. By adopting this approach, we achieved a mean less clean soil level (33.8) which was somewhat more than twice the mean of the clean distribution (15.9). The actual circulation in both Germany and the Netherlands lies in between these extreme values. The soil level distribution of counterfeits was similar in all eight test sets. *Figure 3-2* and *Figure 3-3* show the soil level distribution within the test sets on a scale from 1 to 16, which is linearly related to the scale of 1 to 100 from the quality survey.

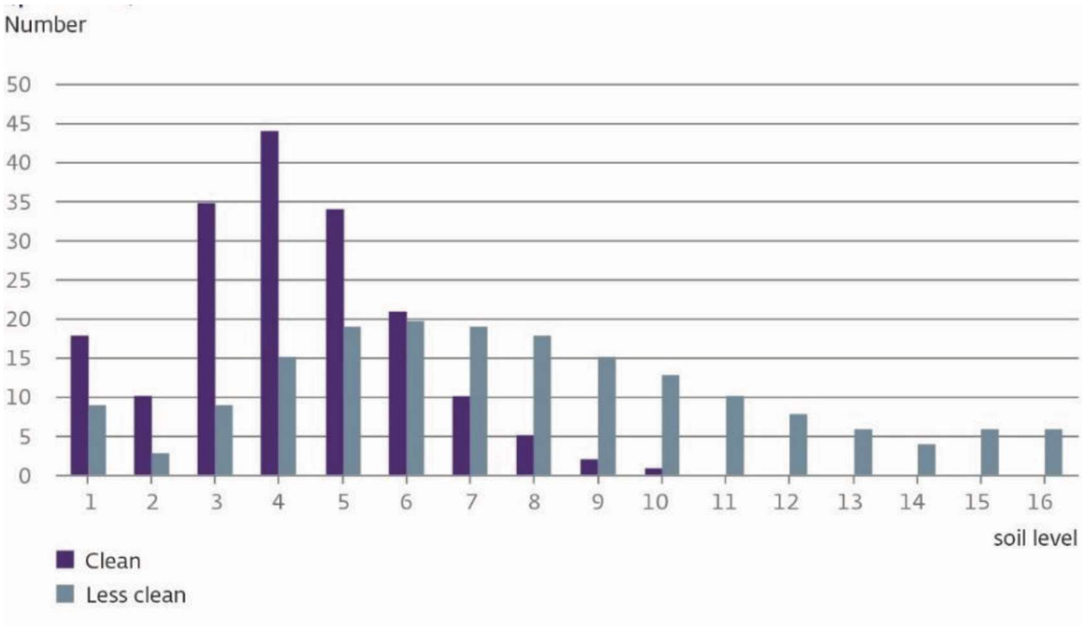

Figure 3-2: Soil level distribution of genuine banknotes in test sets (per set).

To monitor the level of cleanliness before, during and after the tests, some test sets were analysed using Brain^2 technology (Balke, Geusebroek & Markus, 2012). This technology is a quick and reliable means of quality scoring used to decide, for example, whether a banknote that was paid in at a central bank is still suitable for recirculation in terms of cleanliness and possible damages (fitness). It makes use of a self-learning algorithm to determine the fitness probability of a banknote. The Brain^2 fitness detector enabled us to keep track of the average fitness level of the test sets. The assumption was that the banknotes decrease in cleanliness level simply by being used for testing, but the average difference between the clean and less clean sets will remain constant, as they are tested an equal number of times. This assumption appeared to be fairly accurate. Based on measurements of a sample, the Brain^2 fitness score of less clean notes appeared to deteriorate slightly more (decrease in average fitness probability: 15%) than the score of clean notes (12%). The percentage distance between the average fitness probability of clean and less clean sets according to Brain^2 remained very clear both before the testing (15%) and after the testing (19%).

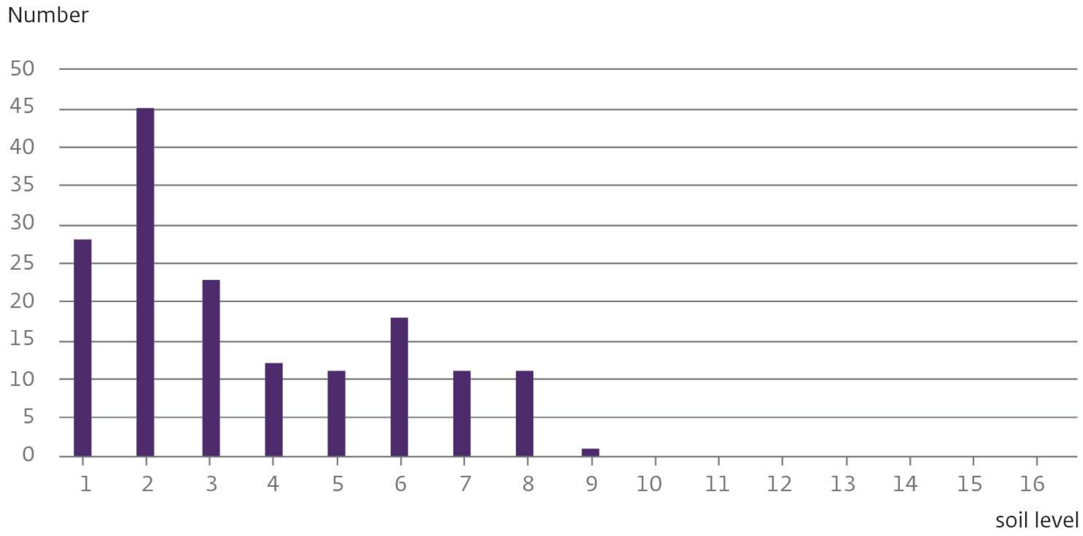

Figure 3-3: Soil level distribution of counterfeits in test sets (total of all 8 sets).

3.2.4 Test setting

The tests took place right after the participants were contacted. Consumers were invited into a special room to take the tests, whereas cashiers took the test in the back office of their workplace during working hours. Test conditions, e.g. lighting conditions, were fairly similar, but this could not be controlled for practical reasons.

Seated at a table, the participants were asked to separate their test sets consisting of 200 banknotes into genuine and counterfeit notes. They were told that their sets consisted of mostly genuine notes, but that there was at least one counterfeit in each stack. The banknotes were offered in five consecutive stacks of 40 notes to each participant in the same random order. The time taken to check each stack of notes was measured using a stopwatch. The reason for not presenting all 200 notes at once was to avoid boredom and to allow participants to take a break after each stack. This was also achieved by allowing a short period of time to note down the counterfeits and the time taken. Despite the fact that the time was recorded, we emphasised to the participants that they should take as much time as they needed, as it was not a competition.

As each central bank disposed of four test sets of banknotes, the tests were mostly conducted in groups of four. In the case of cashiers, the number of participants was sometimes lower, depending on the number of cashiers available in the respective branch. To prevent cheating, each test set was unique with regard to the respective order of the notes. Furthermore, participants were instructed not to pay any attention to others and they were also supervised by the test leaders (at least two test leaders in a test with four participants). We also explained to participants that the results of their peers had nothing to do with their own performance.

Participants were not rewarded for a good test result. However, as most participants were interested in learning about their own counterfeit recognition skills, they were very keen to correctly sort the banknotes into two piles.

After the test, participants were asked to fill in a questionnaire, which included questions on sociodemographic factors. Furthermore, they were asked to write down the security features they had checked. A sample questionnaire can be found in the electronic appendix (A).

3.2.5 Sample size

The aim of the study is to obtain meaningful results for both consumers and cashiers with a statistical power level of 0.8 and a probability level of 0.05. A pilot of 40 candidates yielded a Cohen's d of 0.32 (based on mean differences and standard deviations of the hit rates comparing candidates with clean and less clean sets). This converted into a minimum sample size per group of 122 or 244 in total (one-tailed).[6] In the end, we managed to find more than the necessary minimum number of participants. Our results are based on data gathered from 511 participants – 250 consumers and 261 cashiers.

3.2.6 External validity

The external validity of experimental data is always open to debate. Our study also has some weak points, which require the results to be interpreted carefully.

First, participants were aware of the fact that there would be some counterfeits among the banknotes and that they should look for them. In real life, however, people might not think of the possibility of receiving counterfeit money in a transaction. This is true to a large extent for consumers and to a lesser extent for cashiers. According to the data gathered in our questionnaire, only 14% of consumers and 81% of cashiers had checked banknotes for authenticity during the last six months. Most participants in the test might thus have looked more closely and more critically at banknotes than they would have done in real life. As a consequence, the test results must not be interpreted as the probability of a counterfeit being detected in real life. However, as participants probably took a closer look at both the clean and the less clean test sets we still believe that the difference between the two can be interpreted in a sensible way.

Second, the tests were typically performed by four participants at a time. There is empirical evidence that peer presence can lead to higher motivation and better test performance (e.g. Falk & Ichino (2006), Mas & Moretti (2009)). This is a further reason why the participants' test results should not be interpreted as being equal to their performance in real life. However, as peer effects are relevant for participants with regard to both clean and less clean sets they should not distort a comparison between the two groups.

[6] These calculations were made using the A-priori Sample Size Calculator for Student t-Tests (Soper, 2014).

A third concern is the extent to which our sample of consumers and cashiers is representative of the Dutch and the German population. A strong point of the recruitment strategy was that we directly asked potential candidates to participate in our experiments instead of making general announcements and waiting for volunteers. The willingness to participate was very high. This was partly because the topic was interesting (coming into contact with real counterfeit money), and partly because the tests were conducted at a 'convenient' moment. Cashiers were asked to participate during working hours with the permission of their managers while consumers were contacted mostly during their leisure time. This might mitigate self-selection problems common to most experimental studies. A weak point of the recruitment strategy, however, was that around half of the consumers were contacted at locations or events of the two central banks. By doing so, it was easier to fulfil the banks' security regulations with regard to the handling of large amounts of money (more than 50,000 € in total) and – more importantly - counterfeit notes during the tests. However, the approach might have led to a certain preselection of candidates: the volunteers might be more interested in financial topics than the average citizen. Therefore, candidates in our sample might be better at distinguishing counterfeit and genuine banknotes than the wider population. Yet, as clean and less clean test sets are equally affected by this bias, we are still confident that the results of a comparison between the two can be transferred to the population as a whole.

3.3 Empirical strategy

3.3.1 Hypotheses

For the empirical analysis of the experiments, we formulate three hypotheses that follow the ECB's argumentation on the optimum level of banknote quality to combat counterfeits (ECB Decision 2010/14). The basic idea is that in a clean circulation, security features are more clearly visible.

The first hypothesis establishes a general relationship between banknote cleanliness and counterfeit detection.

H1: Respondents detect more counterfeits in a clean banknote circulation than in a less clean banknote circulation.

Hypotheses 2 and 3 describe how the relationship between banknote circulation and counterfeit detection might operate.

H2: A clean circulation makes it easier for respondents to distinguish between counterfeit and genuine banknotes. [7]

[7] Other hypotheses than those of the ECB might be plausible. For example, one might argue that in a less clean circulation, counterfeits are easier to detect because they stand out more than in a clean circulation.

H3: In a clean banknote circulation, respondents are more suspicious and tend to declare more banknotes to be counterfeits.

Our participants differ widely in terms of their sociodemographic characteristics. We therefore also ask whether personal characteristics, such as age, are relevant for their counterfeit detection performance. The results can help to identify vulnerable groups of the population who should be targeted by future education campaigns on counterfeit detection.

3.3.2 Measures of respondents' performance in counterfeit detection

When a respondent examines a banknote in the test set, four outcomes are possible. If the respondent examines a counterfeit banknote, he or she can either

- correctly classify the banknote as counterfeit (hit), or
- incorrectly classify the counterfeit as genuine (miss).

If the respondent examines a genuine banknote, he or she can either

- correctly classify the banknote as genuine (correct reject) or
- incorrectly classify the banknote as counterfeit (false alarm).

Based on these four combinations, we calculate different performance measures as outcome variables for our regression analysis.[8]

In order to test H1, we follow previous research by Klein et al .(2004) and use the respondents' hit rate as the outcome variable. The hit rate (or detection rate) uses information on hits and misses and is simply defined as the number of hits divided by the total number of counterfeits in the test set (20). By comparing the hit rates of candidates with clean test sets and less clean test sets, we can learn whether there is a general relationship between banknote cleanliness and counterfeit detection. However, we cannot tell whether the relationship is caused by better sorting accuracy (H2) or greater suspicion (H3).

To make a decision on H2 and H3, we must also consider a respondent's correct rejects and false alarms. Klein et al. (2004) and Jonker et al. (2006) calculate a false alarm rate (number of false alarms divided by the total number of genuine banknotes in the test set). If respondents with higher hit rates also have lower false alarm rates, we could conclude that the sorting was done more accurately. If, by contrast, the higher hit rate goes hand in hand with more false alarms, then the respondent was simply more suspicious. This kind of reasoning has been statistically operationalised by 'signal detection theory' (SDT), which has been applied in the field of psychophysics for decades.[9] The two basic elements of the theory are sensitivity and response bias. Sensitivity is the ability to distinguish between counterfeits and genuine banknotes (H2). The response bias describes the general tendency to answer yes or no in a yes/no

[8] The terms used for the four outcomes are derived from the terminology of signal detection theory described later in this section.
[9] See Stanislaw and Todorov (1999) for an extensive discussion.

task. Applied to our experiment, this is the tendency to declare a banknote as counterfeit (H3).

Different measures of sensitivity and response bias have been suggested in the literature. The two prevalent measures for sensitivity are known in the literature as A' and d'. Response bias is operationalised with the measures β and c. All of these measures are functions of the hit rate and the false alarm rate, as described above. Their formulas are given in the electronic appendix C. The actual values of these four measures do not have a simple intuitive interpretation. Except for A', the measures are parametric, i.e. they are based on the assumption that to a respondent, the 'signals' of both genuine and counterfeit banknotes are normally distributed with the same variance but with different means. The corresponding dimension could be called 'counterfeit resemblance' or 'counterfeit obviousness'. The location parameters of the signals along this dimension axis are specific to the individual. In other words, both signals are normally distributed but each individual perceives them in a specific way and then decides accordingly. A respondents' ability to separate the counterfeit signal from the genuine signal is referred to as the individual's sensitivity.

If a person cannot differentiate at all between genuine and counterfeit banknotes, the two distributions have the same mean – in other words, they overlap completely. For a person who does not make any mistakes (no misses or false alarms), there is no overlap in the distributions, which is equivalent to saying that their means are very far apart. Following these considerations, the sensitivity measure d' gives the distance between the means of the two distributions.

An overlap between the two distributions means that there are a number of cases where the individual is not sure whether a banknote is genuine or counterfeit. In such cases, some people tend to say that the banknote in question is counterfeit, which results in a high hit rate, but also a large number of false alarms. Others tend to say that the banknote is genuine, which maximises the number of correct rejects, but also produces several misses. This tendency is called bias. The former type of person is said to have a liberal criterion, while the latter type has a conservative criterion. β and c both measure the position of this criterion with respect to a neutral point, where the standard scores of the probabilities for hits are the same as the standard scores for the probabilities for false alarms. c gives the distance from the criterion to the neutral point in standard deviation units, while β is a likelihood ratio.

A' is a non-parametric measure of sensitivity, i.e. no assumptions are made about the distribution of genuine and counterfeit banknotes along the 'counterfeit resemblance' scale. The main driver of A' is the distance between the hit rate and the false alarm rate. The larger it is, the larger A' is. When an individual is not able to differentiate between counterfeit and genuine notes, the hit rate and the false alarm rate will be the same. One example is a person who declares all banknotes to be counterfeits. This person has a hit rate and a false alarm rate of one. The difference between the two rates is zero, thus indicating that the person is not able to discriminate between the two types of banknotes. In that case, A' takes on its lowest possible value. A' is at its maximum when the hit rate is one and the false alarm rate is zero.

In performance tests, A' and c as well as β and d' can only be used pairwise, respectively. The pairs are equivalent from a methodological perspective. In this paper, we use A' as a measure of sensitivity and c to capture response bias.[10] They are calculated on the level of the individual, i.e. we end up with one value for each of the two measures and for each participant. The parametric measure c is not defined when the hit rate and/or the false alarm rate are zero or one. Therefore, we set the maximum hit rate to 0.975 and the minimum false alarm rate to 0.025.[11,12]

3.3.3 Regression analysis

We estimate several linear regression models with the individual *i* as the level of observation. Each model is in the form

$$y_i = \alpha_0 + \alpha_1 \text{clean}_i + \gamma' X + \varepsilon_i \tag{1}$$

In order to test H1, H2 and H3, the dependent variable *y* is defined as hit rate, sensitivity (A') or response bias (c), respectively.

The main explanatory variable, *clean*, is an indicator variable which assumes the value of one if the respondent has a clean set and the value of zero if the participant has a less clean set during the test. The matrix *X* contains several individual-specific variables: age, gender, level of education, his/her preferred method of payment (cash, cashless or both), whether the respondent is a professional cashier, whether the respondent was impaired by any visual handicaps during the test (any kind of handicap according to their own judgement), whether the respondent had checked banknotes for authenticity in the last six months and a country indicator (Dutch/German). α_0 is a constant, α_1 is a coefficient, γ is a vector of coefficients and ε_i is an error term. In the regression testing H1 and H2, we expect α_1 to be positive. If H3 holds, α_1 will be negative. In an alternative version of the model, we will also allow the marginal effect of *clean* to differ for cashiers and consumers by including an interaction term.

As the assignment of the test sets was completely random, *clean* should in theory be an exogenous variable and a univariate analysis should already give us a causal effect. Nevertheless, we decided to conduct a multivariate analysis for two reasons: first, it is the more conservative method if randomness is violated and candidates with clean sets and less clean sets differ in characters that determine counterfeit detection. Second, the inclusion of socio-economic control variables offers interesting insights into the public's ability to detect counterfeits.

The regression analysis is based on an OLS estimation. Since two of our dependent variables, hit rate and sensitivity, can take on values between (and including) zero and

[10] For an analysis using β and d´ please see the electronic appendix D.
[11] The caps must not be any closer to 1/0 to avoid violating the normality assumption underlying the various signal detection theory measures. 45.4% of our respondents, who have 4 or less false alarms and thus a false alarm rate of below 0.025, are affected by the cap. The cap on the hit rate only affects respondents who have a hit rate of exactly one (26.6% of respondents).
[12] Hit rates of zero (i.e. no counterfeit banknotes are detected) and false alarm rates of one (i.e. all genuine banknotes are classified as counterfeits) do not occur in the dataset.

one, fractional response models might also be appropriate. This is particularly true as we have a high share of respondents with a hit rate of exactly one. In a robustness check, fractional logit and probit estimations of equation (1) produce virtually the same results as the linear model (see the electronic appendix E). We opt for the linear model because it is the more reliable model when standard errors are not identically and independently distributed. We calculate clustered standard errors at the set level to account for the fact that respondents who sort the same test sets might have more similar results.

Each regression is run separately. As our regression equations are all based on the same sample and contain the same explanatory variables, errors are correlated across equations and an estimation in a system (SUR) would enhance efficiency. However, this approach requires standard errors to be independent across individuals which, in our case, is violated because they are clustered at the level of sets. Therefore, we decided to treat equations as independent and estimate clustered standard errors.

3.4 Sample and descriptive statistics

The overall quality of the data derived from the tests is very good. Missing or ambiguous answers were clarified during the interview. For the few inconsistencies remaining, we make simple imputations.[13]

3.4.1 Consumers

Descriptive statistics for the consumer sample can be found in *Table 3-1*, column 1. 250 consumers were interviewed in total. Respondents performed quite well during the tests: the average detection rate was 79% and the false alarm rate was 8%. In the study by Jonker et al. (2006), Dutch consumers attained a hit rate of 92% and a false alarm rate of 14%. However, the test settings differ significantly. First, half of the respondents in the latter study received training on counterfeit detection before starting the test. Second, they needed more time (up to 15 seconds) to examine the banknotes and were allowed to use an electronic checking device. Third, the test was split into three rounds and participants were informed about the percentage of correct answers after each round. Non-trained consumers identified 83% of counterfeits in the first test round, which is close to our own results.

The sensitivity and bias measures A' and c do not have a simple intuitive interpretation. However, some general observations are possible. A' usually lies between 0.5 and 1, where 1 indicates a perfect performance. The average A' of consumers is over 0.9, which implies that respondents do very well in distinguishing counterfeits from genuine banknotes. The bias measure c may be both positive and negative, with zero as the neutral point. A positive value implies a tendency to answer ‘no’, i.e. not to declare a banknote as being a counterfeit. In other words, respondents apply a conservative

[13] For details on the imputation, see the electronic appendix B.

criterion and only call a banknote a counterfeit when they are fairly confident that they are right.

Table 3-1. Descriptive statistics: consumers vs. cashiers.

Variables	Consumers	Cashiers	p-value of t-test	p-value of chi-squared test
Hit rate (Detection rate)	0.792	0.882	0.000	-
	(0.200)	(0.144)		
False alarm rate	0.083	0.048	0.000	-
	(0.103)	(0.062)		
Share of banknotes selected	0.153	0.131	0.000	-
	(0.094)	(0.058)		
Dutch	0.504	0.406	-	0.026
Age	47.744	37.969	0.000	-
	(16.977)	(13.722)		
Female	0.448	0.770	-	0.000
No secundary education	0.028	0.023	-	0.719
Secondary education or education missing	0.276	0.517	-	0.000
Higher secondary education	0.236	0.314	-	0.048
University	0.460	0.146	-	0.000
Visual handicaps during the test	0.068	0.046	-	0.282
Prefers cash as payment instrument	0.244	0.230	-	0.708
Prefers cards as payment instrument	0.372	0.287	-	0.042
No payment preference or missing	0.384	0.483	-	0.024
Has checked banknotes in the last 6 months	0.144	0.812	-	0.000
A'	0.916	0.955	0.000	-
	(0.072)	(0.045)		
c	0.265	0.170	0.007	-
	(0.430)	(0.365)		
Number of security features checked	2.507	3.063	0.024	-
	(0.920)	(0.721)		
Average sorting time per banknote (in seconds)	6.291	5.042	0.000	-
	(2.688)	(2.097)		
Number of observations	250	261	-	-

Notes: Columns 1 and 2 present sample means and standard deviations in parentheses. Column 3 provides p-values of a two-sided t-test on whether the sample means of the continuous variables in the cashier and the consumer sample are the same. Column 4 provides p-values of a chi-squared test on whether the distribution of the indicator variables in the cashier and the consumer sample are the same.

The average time required per banknote was 6.29 seconds, which is close to the 6 seconds we indicated as the time that should suffice to recognise a counterfeit. However, further analysis shows that the time needed per banknote varied widely, from 1.9 to 17.0 seconds, and it markedly decreased from stack to stack. With regard to sociodemographic factors, our sample of consumers comprises more males and more persons with an above-average level of education compared to the population in Germany and the Netherlands as a whole. There are an equal number of German and Dutch participants. Only a small minority of consumers (14%) have recently checked banknotes for authenticity. In the tests, they checked 2.43 security features on average. This is in accordance with the number of security features spontaneously mentioned by Dutch respondents (between 1.9 and 2.6) in the biennial studies about knowledge and appreciation of euro banknotes (Randsdorp & Zondervan, 2015). In theory, this should be sufficient to follow the ECB’s advice always to check multiple security features.

3.4.2 Cashiers

Column 2 of Table 3-1 shows summary statistics for the cashier sample. Columns 3 and 4 show the results of t-tests and chi-squared tests on whether the summary statistics significantly differ between cashiers and consumers. In total, 261 cashiers were interviewed in our study – 106 in the Netherlands and 155 in Germany. The cashiers were significantly quicker and better at detecting counterfeits than consumers. The hit rate was 88% and the false alarm rate only 5%. Again, the cashiers’ performance was worse than in the study by Jonker et al. (2006) (see the discussion in section 4.1). The average of the sensitivity measure A' was higher for cashiers than for consumers, which implies that they were better at distinguishing between counterfeit and genuine banknotes. The bias measure c indicates that in case of doubt, cashiers were more prone to call a banknote a genuine banknote rather than a counterfeit, just as consumers are.

In contrast to consumers, the cashiers were significantly younger, the proportion of females was significantly higher and their average (completed) level of education level was significantly lower. However, many cashiers in the retail business are young people studying at university, who have not yet reached the final level of education that they are aiming for. The preference for cash as a payment instrument was about the same as for consumers (23% vs. 24%), but 37% of consumers and only 29% of cashiers prefer cards.

Most cashiers have checked banknotes in the last six months. However, some of them have not checked them manually, only using banknote authentication devices. The average number of security features checked was slightly higher for cashiers than for consumers.

3.4.3 Descriptive statistics on the level of sets and stacks

Table 3-2 shows summary statistics distinguishing between candidates with clean sets (column 1) and candidates with less clean sets (column 2) as well as the results of t-tests and chi-squared tests on whether the statistics significantly differ between the two groups (columns 3 and 4). The table provides initial evidence that the cleanliness of banknotes does actually play a role when it comes to detecting counterfeits. The hit rate was significantly higher in the clean sets (0.86) than in the less clean sets (0.82).

However, the clean sets also show a significantly higher rate of false alarms (0.07 vs 0.06).

Table 3-2. Descriptive statistics: clean sets vs. less clean sets

Variables	Clean sets	Less clean sets	p-value of t-test	p-value of chi-squared test
Hit rate (Detection rate)	0.858	0.817	0.009	-
	(0.173)	(0.182)		
False alarm rate	0.072	0.058	0.055	-
	(0.091)	(0.080)		
Share of banknotes selected	0.151	0.134	0.013	-
	(0.082)	(0.073)		
Dutch	0.449	0.459	-	0.827
Cashier	0.512	0.510	-	-
Age	42.402	43.102	0.625	-
	(16.863)	(15.414)		
Female	0.609	0.616	-	0.884
No secundary education	0.039	0.012	-	0.050
Secondary education or education missing	0.383	0.416	-	0.448
Higher secondary education	0.305	0.247	-	0.145
University	0.273	0.325	-	0.199
Visual handicaps during the test	0.078	0.035	-	0.036
Prefers cash as payment instrument	0.230	0.243	-	0.736
Prefers cards as payment instrument	0.316	0.341	-	0.551
No payment preference or missing	0.453	0.416	-	0.393
Has checked banknotes in the last 6 months	0.500	0.471	-	0.506
A'	0.940	0.932	0.189	-
	(0.062)	(0.063)		
c	0.145	0.289	0.000	-
	(0.400)	(0.389)		
Number of security features checked	2.527	2.552	0.794	-
	(1.092)	(1.117)		
Average sorting time per banknote (in seconds)	5.692	5.614	0.724	-
	(2.467)	(2.501)		
Number of observations	256	255	-	-

Notes: Columns 1 and 2 present sample means and standard deviations in parentheses. Column 3 provides p-values of a two-sided t-test on whether the sample means of the continuous variables in the clean and the less clean sample are the same. Column 4 provides p-values of a chi-squared test on whether the distribution of the indicator variables in the clean and the less clean samples are the same.

Thus, more counterfeits were detected in the clean sets, but more genuine banknotes were also incorrectly declared as being counterfeits. As for A', differences between clean and less clean sets were small or non-existent. The average value of c is lower in the clean sets, which points towards a tendency to declare more banknotes as being counterfeits when the cleanliness of the circulation is high. The average sorting time was similar in both types of sets. The sociodemographic profile of participants sorting the clean and less clean sets is similar with two exceptions: in the clean sets there is a significantly higher share of candidates without a secondary education and with visual handicaps.

3.5 Regression results

3.5.1 H1: Hit rate

Table 3-3 shows the regression output for equation (1) with the hit rate as a dependent variable. Column 1 presents the results of a univariate analysis that only comprises *clean* as an explanatory variable. Column 2 presents the results of a multivariate analysis with the control variables contained in *X.* In column 3 we allow the effect of *clean* to differ between cashiers and consumers by including an interaction term.

In both the univariate and the multivariate regression, the coefficient of *clean* is positive and significant at the 5% level. Having a clean set raises candidates' hit rates by an average of 4 percentage points. Relative to the average detection rate of 84%, this corresponds to a 5% rise. Thus, there is a positive relationship between banknote quality and counterfeit detection (H1).

The coefficients of the covariates show some further interesting results. German candidates detect more counterfeit banknotes than Dutch consumers. The reason for this might be that participants in Germany and the Netherlands were recruited in different ways. In Germany, most of the consumers were interviewed during events organised by the Deutsche Bundesbank, such as at an 'Open Day' or during Bundesbank presentations targeted at the general public. As a result, German participants might have an above-average level of interest in central banking topics.

The age of the respondent has a significant negative effect on the hit rate. The older the person, the fewer counterfeits he or she detects. Our model predicts that a 25 year old candidate with otherwise average characteristics (sample means) will find 90.6% of all counterfeits, while a 65 year old candidate will detect only 75.3%.

The variables indicating a candidate's secondary education show no significant effect. This is surprising as one would expect these variables to be a good proxy for the candidate's cognitive skills and thus should be positively correlated with the detection rate. One possible explanation for the missing effect is that we lack information on income which is highly correlated with education but might have a negative effect on the detection rate: people with a higher income might not be too worried about a potential financial loss resulting from accepting a counterfeit banknote and are therefore less well informed about how to recognise counterfeit banknotes.

Table 3-3. Results from different linear regression models with the hit rate as a dependent variable

Variables	(1)	(2)	(3)
Clean set	0.041**	0.040**	0.032
	(0.017)	(0.013)	(0.021)
Dutch	-	-0.052***	-0.052***
		(0.011)	(0.011)
Age	-	-0.004***	-0.004***
		(0.000)	(0.000)
Female	-	-0.033	-0.033
		(0.023)	(0.023)
No secundary education	-	-0.047	-0.046
		(0.041)	(0.041)
Secondary education or education missing	-	Ref.	Ref.
Higher secondary education	-	0.011	0.012
		(0.015)	(0.015)
University	-	0.022	0.022
		(0.020)	(0.020)
Visual handicaps during the test	-	-0.040	-0.040
		(0.027)	(0.027)
Prefers cash as payment instrument	-	Ref.	Ref.
Prefers cards as payment instrument	-	0.033**	0.034**
		(0.010)	(0.010)
No payment preference or missing	-	0.017	0.017
		(0.016)	(0.016)
Has checked banknotes in the last 6 months	-	0.069**	0.069**
		(0.023)	(0.022)
Cashier	-	0.019	0.011
		(0.035)	(0.039)
Clean set x Cashier	-	-	0.015
			(0.030)
Constant	0.817***	0.957***	0.961***
	(0.011)	(0.023)	(0.020)
Number of observations	511	511	511

Notes: The table presents estimated coefficients and robust standard errors of a linear regression model with the hit rate as a dependent variable. Standard errors are clustered at the set level. Statistical inference is based on two-sided t-tests. *, **, and *** indicate statistical significance at the ten, five, and one percent level, respectively.

As for payment behaviour, candidates who prefer to pay by cashless means have a higher hit rate than those who predominantly use cash. This comes as a surprise as one would expect candidates who regularly handle banknotes to be more familiar with them and consequently perform better in the tests. One possible explanation for the unexpected correlation pattern is unobserved heterogeneity among participants, such as cognitive abilities. High cognitive skills are probably helpful in detecting counterfeits. At the same time, a study by Kalckreuth et al. (2014) establishes a correlation between cash usage and lower cognitive skills.

Having checked banknotes in the last six months increases the hit rate. This is either because these candidates must dispose of some kind of knowledge on how to identify counterfeits or because these candidates are more suspicious by nature and sort out more banknotes.

Surprisingly, we find no significant effect in terms of whether a candidates is a professional cashier or not, even though on a descriptive basis, the difference in hit rates was rather pronounced (see *Table 3-1*). A more detailed analysis shows that in the regression, the effect of the indicator variable for cashiers is entirely captured by the indicator showing whether the candidate has recently checked banknotes for authenticity. Apparently, handling banknotes regularly does not per se give cashiers an advantage when it comes to detecting counterfeits. The decisive factor appears to be that during their work they consciously examine the banknotes they handle.

In column 3 we also allow the effect of clean to differ between cashiers and consumers by including an interaction term. The coefficient of the interaction term is very small and insignificant.[14] It would appear that a clean banknote circulation does not help cashiers to detect counterfeits any more than it does for consumers.

3.5.2 H2: Sensitivity

In a next step, we investigate whether banknote cleanliness affects participants' sensitivity A' (Table 3-4) The coefficient of cleanliness is not significant, neither in the univariate regression (column 1) nor in the multivariate regression (column 2). Thus, having a clean set does not help in distinguishing genuine banknotes from counterfeits (contradicting H2). As can be seen from the interacted regression in column 3, this result holds for both consumers and cashiers.[15]

Interestingly, all explanatory variables besides cleanliness have a similar effect on sensitivity as they do on the hit rate: being young, German, preferring card payments, checking banknotes for authenticity and having no visual impairment significantly increases sensitivity.

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[14] This result also holds if we estimate a model that only contains indicators for *clean*, *cashier* and the interaction term between the two variables.

[15] Using the alternative sensitivity measure d' as a dependent variable leads to very similar results with regard to both sign and significance of the estimated coefficients (see the electronic appendix D).

Table 3-4. Results from different linear regression models with sensitivity measure A' as a dependent variable

Variables	(1)	(2)	(3)
Clean set	0.007	0.007	0.003
	(0.008)	(0.004)	(0.007)
Dutch	-	-0.022***	-0.022***
		(0.004)	(0.004)
Age	-	-0.001***	-0.001***
		(0.000)	(0.000)
Female	-	-0.015	-0.016
		(0.009)	(0.009)
No secundary education	-	-0.026	-0.025
		(0.017)	(0.017)
Secondary education or education missing	-	Ref.	Ref.
Higher secondary education	-	0.005	0.005
		(0.006)	(0.006)
University	-	0.004	0.004
		(0.008)	(0.008)
Visual handicaps during the test	-	-0.011	-0.011
		(0.008)	(0.008)
Prefers cash as payment instrument	-	Ref.	Ref.
Prefers cards as payment instrument	-	0.016**	0.016**
		(0.007)	(0.007)
No payment preference or missing	-	0.009	0.009
		(0.009)	(0.009)
Has checked banknotes in the last 6 months	-	0.026**	0.026**
		(0.009)	(0.009)
Cashier	-	0.015	0.012
		(0.014)	(0.018)
Clean set x Cashier	-	-	0.006
			(0.013)
Constant	0.932***	0.968***	0.970***
	(0.005)	(0.008)	(0.007)
Number of observations	511	511	511

Notes: The table presents estimated coefficients and robust standard errors of a linear regression model with the sensitivity measure A' as a dependent variable. Standard errors are clustered at the set level. Statistical inference is based on two-sided t-tests. *, **, and *** indicate statistical significance at the ten, five, and one percent level, respectively.

3.5.3 H3: Bias

Table 3-5 shows the regression results with the bias measure c as the dependent variable. As can be seen from the negative coefficients of the clean set indicator in both the univariate (column 1) and multivariate regression (column 2), clean banknotes reduce participants' bias measure c. This result holds for consumers and cashiers alike (column 3). In accordance with H3, they become more suspicious when the set is clean and are more likely to declare a banknote a counterfeit in case of doubt.[16]

As brand new banknotes are often mistaken for counterfeits they appear to be an important driver of the strong bias in the clean sets. Their false alarm rate is 14.7% versus 5.8% for the remaining, less clean banknotes.[17] The answers in the questionnaire on the candidates' testing strategy suggest that the 'feel' of the brand new banknotes is the decisive characteristic which raises suspicion.

As for the socio-economic control variables, older participants apply a more conservative criterion. Older adults are known to very much dislike making errors (Starns & Ratcliff, 2010). What that means depends on what they perceive as the most important error. Since there were far fewer counterfeits than genuine notes in the test sets, they may have considered a false alarm to be the most embarrassing error, which could have led to the conservative bias for older adults.

Candidates who have recently checked banknotes for authenticity have a lower bias measure c. This is as expected because candidates who are more inclined to check banknotes in real life should also be more suspicious during the tests. Professionals are no more suspicious than consumers (even if we leave out the indicator for recent banknote checks).

[16] Again, using an alternative bias measure β instead yields largely the same results (see the electronic appendix C).

[17] The difference between the two rates is statistically significant at the one percent level based on a two-sided t-test *($p = 0.000$)*.

Table 3-5: Results from different linear regression models with bias measure c as a dependent variable

Variables	(1)	(2)	(3)
Clean set	-0.144***	-0.143***	-0.118*
	(0.030)	(0.028)	(0.055)
Dutch	-	0.049*	0.050*
		(0.022)	(0.021)
Age	-	0.008***	0.008***
		(0.000)	(0.000)
Female	-	0.020	0.021
		(0.037)	(0.037)
No secundary education	-	0.071	0.068
		(0.110)	(0.110)
Secondary education or education missing	-	Ref.	Ref.
Higher secondary education	-	-0.002	-0.003
		(0.037)	(0.037)
University	-	-0.048	-0.047
		(0.037)	(0.037)
Visual handicaps during the test	-	0.045	0.045
		(0.062)	(0.062)
Prefers cash as payment instrument	-	Ref.	Ref.
Prefers cards as payment instrument	-	-0.005	-0.006
		(0.045)	(0.045)
No payment preference or missing	-	0.027	0.027
		(0.027)	(0.028)
Has checked banknotes in the last 6 months	-	-0.081*	-0.081*
		(0.038)	(0.037)
Cashier	-	0.020	0.044
		(0.056)	(0.043)
Clean set x Cashier	-	-	-0.048
			(0.068)
Constant	0.290***	-0.057	-0.072
	(0.012)	(0.059)	(0.055)
Number of observations	511	511	511

Notes: The table presents estimated coefficients and robust standard errors of a linear regression model with the bias measure c as a dependent variable. Standard errors are clustered at the set level. Statistical inference is based on two-sided t-tests. *, **, and *** indicate statistical significance at the ten, five, and one percent level, respectively.

3.6 Conclusions and recommendations

The purpose of this study was to improve knowledge about the effect of cleanliness of the banknote circulation on counterfeit detection. We tested 250 consumers and 261 cashiers from the Netherlands and Germany, using eight different test sets of two different cleanliness levels, each consisting of 20 counterfeits and 180 genuine banknotes. The empirical analysis of the experiment was based on four different performance measures – hit rate, false alarm rate, sensitivity and bias – which allowed us to draw a differentiated picture of the relationship between cleanliness and counterfeit detection.

As a first measure, we studied the testees' hit rate, which is the proportion of correctly selected counterfeits. The average hit rate for consumers was 79%, and 88% for cashiers. Conducting a regression analysis, we find that hit rates are on average 5% higher when the sorted banknotes are clean. These results suggest that there is indeed a positive relationship between banknote cleanliness and the detection of counterfeits.

However, the high detection rates in the clean sets of our sample are accompanied by a large number of false alarms. This leads to two further questions: did the clean banknotes actually make it easier for the candidates to distinguish between counterfeit and genuine banknotes? Or did they only raise the suspicion of the candidates, who then declared more banknotes to be counterfeits, correctly or not?

To answer these questions, we adopted two concepts from signal detection theory. The measure of sensitivity describes the ability to distinguish between genuine and counterfeit banknotes. The measure of bias shows a candidate's tendency to be more or less suspicious about genuineness in general. Our results suggest that cleanliness does not help to increase sensitivity but rather drives up bias: people are generally more suspicious when the average cleanliness of banknotes is good.

When transferred to real life, our results suggest that high sorting standards can indeed increase counterfeit detection rates in the economy. In our tests, consumers and cashiers alike detected more counterfeits when the surrounding banknotes were clean. With high sorting standards, more counterfeit banknotes could be detected at the cash desks. However, our results also show that better sorting standards do not help the public to actually distinguish between counterfeit and genuine banknotes. The higher detection rates in the clean sets are rather the consequence of the testees' being more suspicious towards new banknotes in general. Thus, in real life, raising sorting standards also has an important drawback: consumers and cashiers are inclined to examine banknotes more closely, which increases transaction costs and in some cases might even lead to embarrassing situations at the cash desk. Furthermore, there is a risk that hit rates will go down again if people adapt to higher sorting standards and become less and less suspicious towards new and clean banknotes. Because of this trade-off, our results do not allow us to make any clear-cut recommendations regarding sorting standards. In addition, substantial costs can arise from replacing more sorted banknotes with new ones. Ultimately, the optimal level of banknote quality in each euro area country will depend on the specific counterfeiting rates, sorting costs, and the public's general expectations regarding the quality of banknotes.

As a further result, we find that brand new banknotes are often mistaken for counterfeits. According to our observations during the tests and comments made by the respondents in the questionnaires, this is mainly caused by the 'feel' of such banknotes. A possible recommendation from our study is therefore to carefully consider the feel of the banknote and the changes in tactile features of the banknotes when decisions about the material and coating of future banknotes are made. Nevertheless, further research on the determinants of bias in counterfeit detection is needed.

Furthermore, the age of the participants is found to be significant in most of our analyses. Older people detect fewer counterfeits and are less sensitive. At the same time, various studies on payment behaviour show that older people use cash more often (see, for example, Deutsche Bundesbank, 2015, pp 32-33). We therefore recommend developing information material targeted at older members of society and considering the needs of the elderly when developing new banknote designs and security features.

4

Finding counterfeited banknotes: the roles of vision and touch[18]

[18]This chapter corresponds to: van der Horst, F., Snell, J., & Theeuwes, J. (2020). Finding counterfeited banknotes: the roles of vision and touch. Cognitive research: principles and implications, 5(1), 1-14.

Central banks incorporate various security features in their banknotes to enable themselves, the general public, retailers and professional cash handlers to detect counterfeits. In two field experiments, we tested central bank counterfeit experts and non-experts (the general public) in their ability to detect counterfeited euro banknotes. We varied exposure duration and perceptual modality (sight, touch or both). The counterfeit banknotes were actual counterfeits taken out of circulation. Experiment 1, in which participants only viewed the banknotes, showed that experts did reasonably well in detecting counterfeits even when exposure duration was limited to 500 ms. Non-experts did not reach the criterion for decent performance, marked by d' = 1.25, although they did perform above chance. In Experiment 2, participants could both see and touch the banknotes, which resulted in better performance especially with longer exposure durations. The main finding of the current study is that visual information mostly impacts the decision process during the first glance, whereas tactile information increasingly aids performance as it continues to be accrued over time. Implications for the design of security features of new banknotes are discussed.

The present study investigated how well experts (bank employees dealing with counterfeiting) and non-experts (the general public) are able to detect counterfeited banknotes. The results show that the general public is able to do this well above chance even when they see the banknote for only 500 ms. Experts performed much better. When non–experts and experts can both see and touch the banknote performance becomes much better especially when there is ample time to check these banknotes. It is recommended that when central bankers design new banknotes, they should continue to consider security features that appeal to both touch and vision.

Keywords: attention, decision-making, gist, vision, touch, authentication, banknotes, counterfeits.

4.1 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). Research has shown that Dutch citizens have strong confidence in the authenticity of euro banknotes because the likelihood of receiving a counterfeit is very low (van der Horst, de Heij, Miedema & Van der Woude, 2017b). For example, in Europe in 2018, the number of counterfeit euro banknotes that were 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 the general public 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 various 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 alto-relievo induced by intaglio printing (raised ink). These authentication features appeal to two of our five senses, namely sight and touch (see Figure 4-1).

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 needed to ensure that the exploitation of these senses prompts at least a decent detection performance. For instance, 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? Additionally, we do not yet know how these factors are influenced by expertise. Specifically, might expertise increase the value of evidence accrued beyond the first impression? The present study is aimed at answering these questions.

4.1.1 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, 2011). In the present context it could be argued that a typical cash transaction would solely involve 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 slower, controlled and conscious decision process, which in the literature has been labelled Type 2 processing (Frankish, 2010; Kahneman, 2011). See Klöne et al. (2019) for a discussion of factors driving a more deliberate banknote verification process.

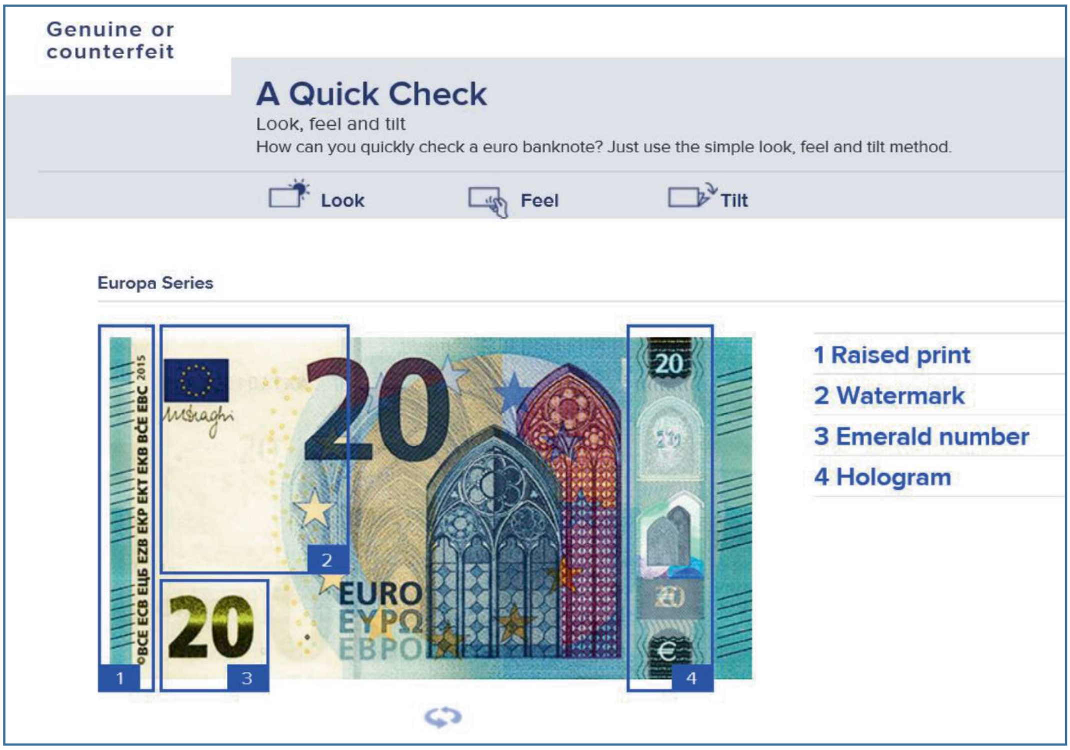

Figure 4-1. Security features for the public shown on the website of DNB[19].

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. The extent to which findings may inform us about Type 1 processes will be addressed in the General Discussion.

It must be stressed that human authentication has its limits even when invoking Type 2 processes . For example, in an experiment in which genuine and manipulated photographs were presented on a computer screen, it was shown that people have poor ability in identifying whether an image is the original or has been manipulated (Nightingale et al., 2017). It has been argued that our inability to detect changes is

[19] www.dnb.nl/echtofvals.

largely driven by the fact that the overall gist of the percept remains unaltered (e.g., Standing et al., 1970).

In addition to limitations in perception, we must highlight the ‘prevalence-effect’. Visual search experiments are perceptual tasks that require 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). However, Wolfe and van Wert showed that when targets were rare (1% prevalence) observers made more than four times the number of ‘miss’ 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, Horowitz and Kenner (2005) showed that if observers repeatedly do not see 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).

4.1.2 About time

The act of accepting a banknote is performed rapidly. An internal DNB cashier field study (Zondervan, Heinen & van den Heuvel, 2019) shows that most cashiers make - implicitly or explicitly and without the use of authenticating devices - the decision of 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. Presumably, 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 noted 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 (see for instance Oliva, 2005; Fei-Fei et al., 2007)). On the other hand, it should be noted that 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, more fine-grained perception is a prerequisite for successful counterfeit detection.

It is generally believed that presenting a display for only 200 ms should be enough for detecting 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, 2011). The recognition and discrimination of patterns appears to take longer. According to Fei-Fei et al. (2007) observers need a presentation time of 500 ms to be able to almost perfectly categorize outdoor and indoor scenes. Furthermore, a study by Greene et al. (2015) showed that participants can make an adequate description of typical real-world situations scenes after 506 ms, although it takes participants longer to understand and even perceive improbable visual images (e.g., a press conference being convened 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 counterfeits from real banknotes. If counterfeits are distinct from genuine banknotes by virtue of features that stand out (e.g., Theeuwes, 1992) 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 (up to) 10 s 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 s, 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 review of the tenets of touch with respect to counterfeit detectability.

4.1.3 Touching on touch

When both visual and haptic perception are available, it is likely that 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 (Tsakiris & Haggard, 2005).

The conception that haptic perception is likely to play a considerable role is further fueled by the fact that it may simply contribute a good deal of new information. Consider, for instance, that when using a banknote, people might see only one side of it, but will always feel both sides.

Haptic perception typically involves active manual exploration. In general, when exploring objects haptically, people tend to rely on their experiences with the external world of surfaces and object properties such as roughness, shape, weight, material characteristics, contour, et cetera. According to Lederman and Klatzky (1987) there are basically six types of haptic exploration: 1) lateral motion, typically used to explore textures; 2) pressure, to determine hardness; 3) static contact, to assess temperature; 4) unsupported holding, for judging weight; 5) enclosure for estimating size; and 6) contour tracking, to determine the shape. With respect to assessing counterfeit banknotes haptically, we hypothesize that lateral motion (exploring texture) and pressure (hardness of the surface) are the most important types of haptic exploration. Note, however, that we do not manipulate or control for the type of haptic exploration used by participants in the present study. Hence, if we are to establish a considerable role for haptic perception, we would not be able to make claims about specific strategies; (and analogously, we will not be able to make claims about specific strategies in the visual domain).

The haptic exploration of banknotes was studied by Wijntjes (2009). This study indicated that a cash handler receiving 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 4-2. 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 its structure and raised ink.

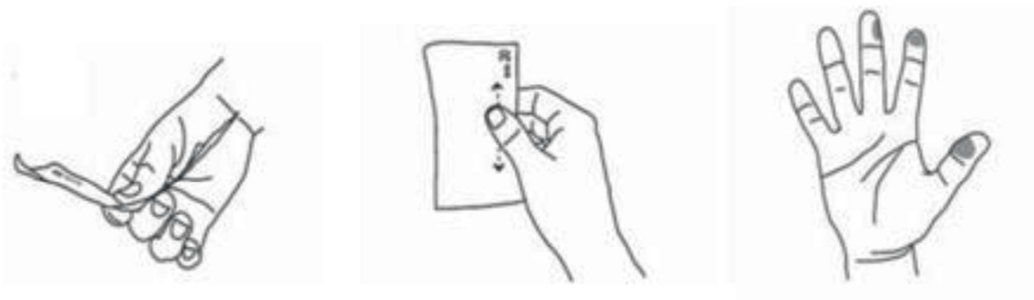

Figure 4-2. Haptic banknote interaction. Left: movement over the surface. Bending of the paper, fingers on two sides. Thumb on the front and index finger on reverse. The middle finger is sideways supporting the index finger. Middle: multiple contact areas. Thumb (and not index finger) is used to rub 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 et al. (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 behaviour 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 & Klatzky, 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 of a banknote is an important feature for detecting counterfeits. The feel includes the paper ('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 used three soil levels and three variants of counterfeits, similar to what according to her is typically seen in actual counterfeits. The results showed that sensitivity to detect counterfeit was adequate across all soil levels, even when very high-quality counterfeits were presented. Raymond concluded that tactile information affords better counterfeit detection than visual information, regardless of soil level.

Next to intaglio, the substrate or matter of the banknote 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 similar 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 being unable to touch them (yielding an 87% detection rate) than vice versa (74%). When sight and touch were combined the detection rate was on average 92%.

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 discriminate physical genuine banknotes and counterfeits by only touching them or by touching and seeing them.

4.2 Method Experiment 1: 'looking' (screen test)

4.2.1 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 time conditions (maximum of 500 ms, 1,000 ms and 10 s). 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. Fourteen Experts participated in Experiment 1.

4.2.2 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 had been tricked in real life by this counterfeit). This means that they had to be taken out of circulation.
- The denominations were those that tend to be counterfeited the most often (EUR 20 and EUR 50 banknotes). (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 4-3). 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 4-1 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 4-3. 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 4-1. Description of our stimulus 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

4.2.3 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 4-4 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 s (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.

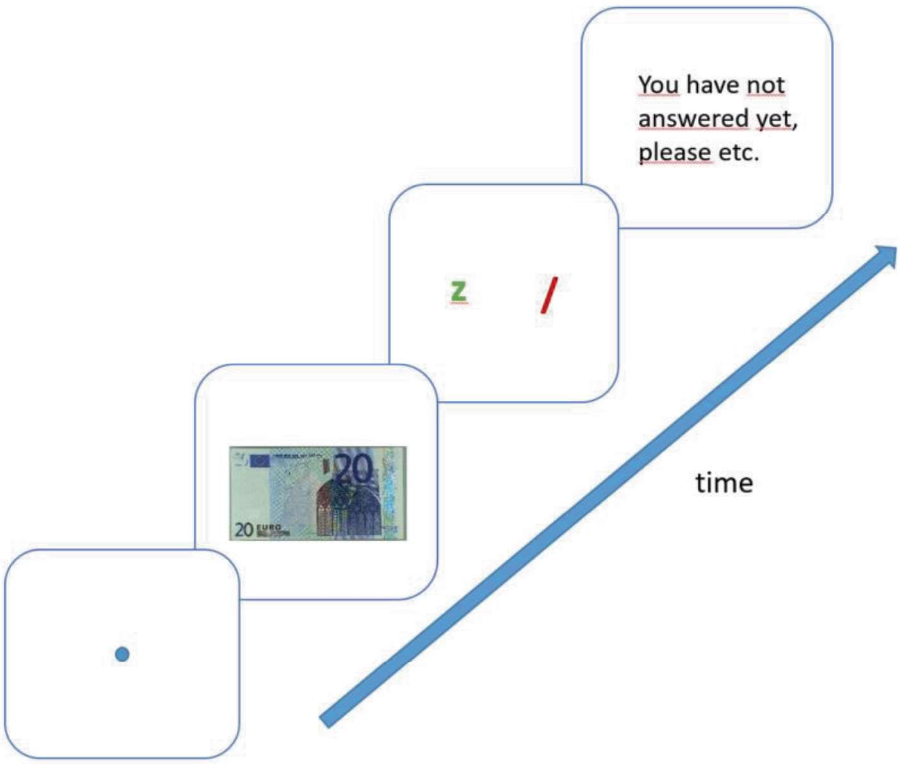

Figure 4-4. Procedure screen test. The core structure of the trial. Every trial started with a fixation dot in the center, for 500 ms, followed by a banknote (either EUR 20 or EUR 50, either genuine or counterfeit, either first or second series). The display duration was either 500 ms, 1,000 ms or maximum 10 s varied between blocks. In case of not pressing the right key a reminder was shown.

4.3 Method experiment 2: 'feel' and 'look and feel' (physical test)

4.3.1 Participants

The method of assessing public and experts was the same as it was in Experiment 1. In total 40 participants (10 experts and 30 non-experts) were tested in Experiment 2. All 10 experts performed the task both in the feel-only condition and in the look-and-feel condition, whereas the 30 non-experts were divided equally between these two conditions.

4.3.2 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.

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 4.2).

Table 4-2. 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 s	4. Taking, seeing and touching the banknote for a maximum of 10 s

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 (feel condition) or in a box in order to prevent participants from seeing the banknotes after they had made their judgement (condition feel and see). 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. In the condition ‘long’ the participant could use up to 10 seconds to explore the banknote haptically before making an assessment. The participant could decide to use the left and/or right hand and make use of different exploratory procedures. Participants showed a large variation of exploratory tactics (fondling, movement over surface, pulling from both ends, et cetera.). As was noted in the Introduction, we did not control for the type of haptic exploration employed by the participants. 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 analyze 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.

4.4 Performance analysis

In order to determine how well participants were able to detect counterfeits we used measures 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.

4.5 Results

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.

Note that series (ES1, ES2) and denominations (EUR 20, EUR 50) were collapsed in all analyses.

4.5.1 Results Experiment 1 (vision)

Figure 4-5 presents the average sensitivity scores for Experiment 1 for all participants, and broken down into 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 differed from each other ($F(2,144)=2.80$, $p=0.0642$), although there was a trend. Most participants, both experts and the general 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: $t(59)=10.98$, $p<0.0001$). Even when taking out the counterfeit that the public recognized most often (in 88% of all displays), sensitivity was still well above chance level: $t(59)=6.63$, $p<0.0001$).

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

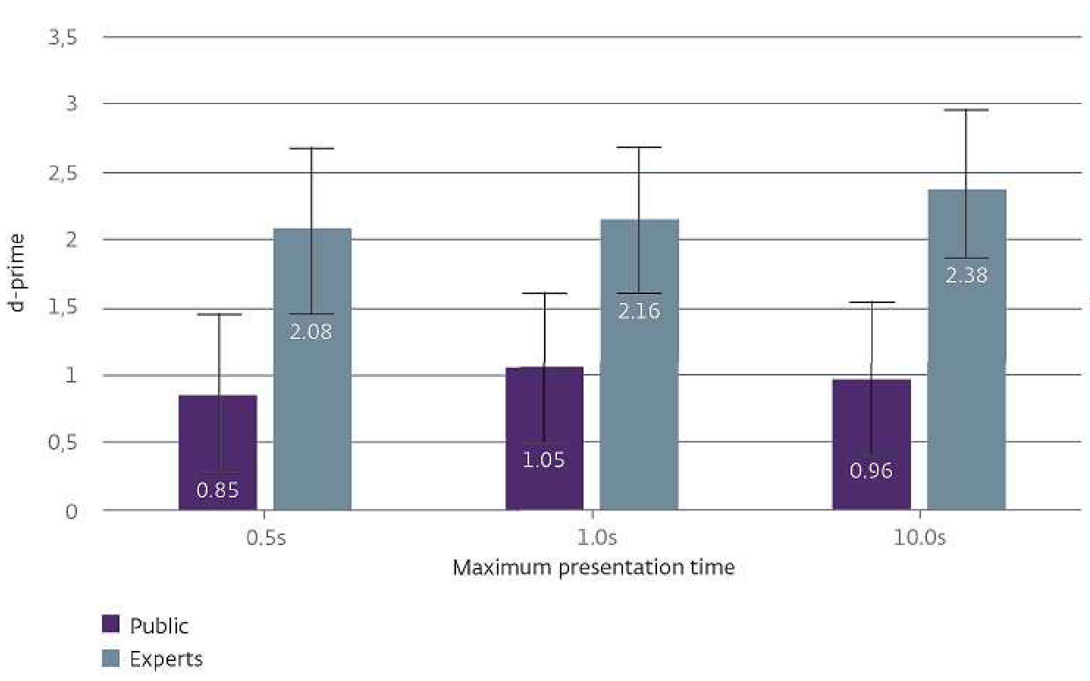

Figure 4-5. Experiment 1 mean sensitivity scores and their error bars (SD) as a function of expertise and exposure time.

Figure 4-6 shows the response times (RTs) for public and experts in Experiment 1. RT was measured as the time from the onset of the stimulus to the pressing of the key on the keyboard. We applied a 2x3x2 mixed model ANOVA on RT with level of expertise as a between-subject factor and exposure time 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 was a main effect of genuineness ($F(1,75)=13.27$, $p=0.0005$). Participants took more time to decide that a banknote was genuine when it was genuine (1.930s) than that they decided that it was counterfeited when it was in fact counterfeited (1.667s). There was an interaction between exposure time and genuineness ($F=8.22$, $p=0.0004$), such that when banknotes were presented only for a short period of time, participants took the same time to authenticate counterfeits and genuine banknotes, whereas when the banknotes were presented for a longer time, participants took more time to classify genuine banknotes ($t(150)=5.39$, $p<0.0001$).

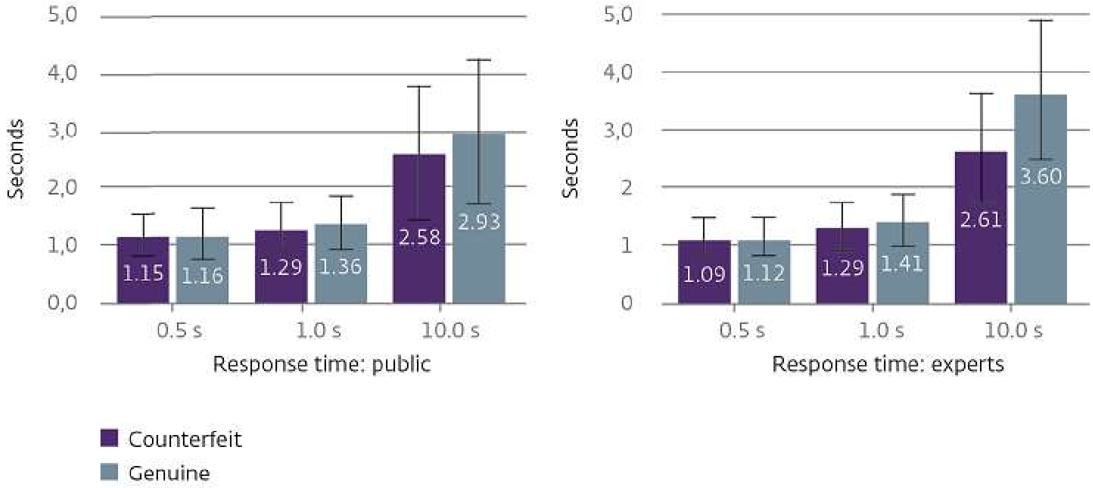

Figure 4-6. Mean response time and their error bars (SD) public (left) and experts (right): Screen conditions.

4.5.2 Results Experiment 2 (physical test)

Figure 7b shows the sensitivity scores for the public and the experts in the second experiment, in which physical banknotes were used. 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 again clearly better than participants from the general public, $F(1,36)=32,77$, $p<0.0001$. The combination of vision and touch led to better performance than solely touching the banknote ($F(1,36)=48.72$, $p<0.0001$). Unlike Experiment 1, when involving touch, exposure time had a significant effect ($F(1,36)=9.90$, $p=0.0033$), with longer exposure times leading to better performance. Importantly, even under the least optimal circumstances (solely touching the banknote briefly) the public ($d' = 0.58$) scored significantly above chance level (one sample t test: $t(14)=2.66$, $p=0.0186$). When taking out the data of the counterfeit that was best recognized (in 14 out of 15 times in the short feeling condition), it was borderline significantly above chance : $t(14)=2.07$, $p=0.0576$.

In the physical test the time it took for each participant to handle each banknote was measured during the experiment and analysed later off line.

Table 4-3 provides the average handling times per condition. A t-test showed that public and expert participants did not differ in handling time: $t(37)=0.42$, $p=0.677$).

Table 4-3. 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

4.5.3 Results of Experiments 1 and 2 combined

In this section we compared the results of Exp. 1 (vision from a computer screen) with the results of Exp. 2 (feel only and feel and look). In this analysis, for the short exposure duration of Exp. 1 we used the 1,000 ms condition, which was more or less comparable to the 1,300 ms short exposure duration of Exp. 2.The results of both tests were combined and analyzed with a three-way mixed ANOVA design, Expertise (2 levels; between) x Exposure time (2 levels; within) x Perceptual modality (3 levels; between).

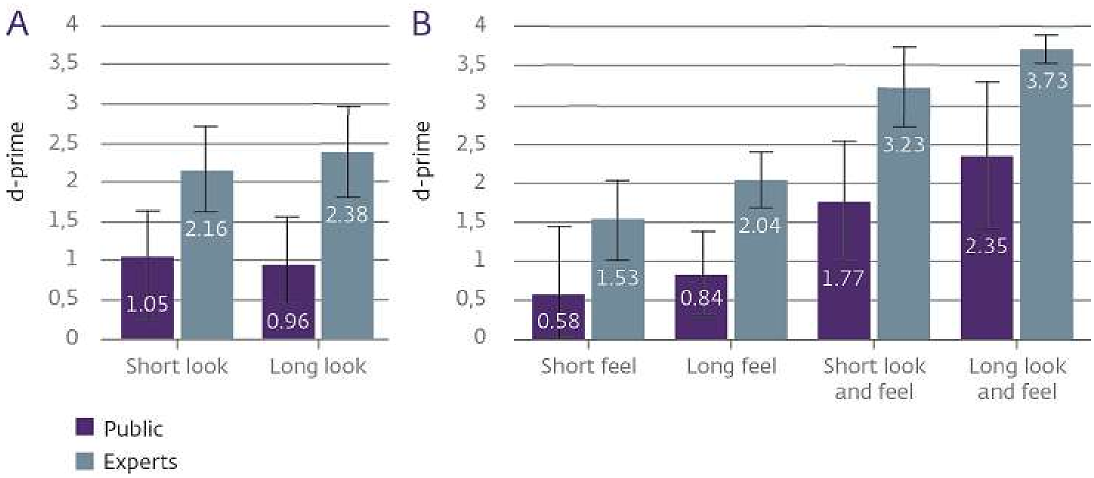

Figure 4-7. Comparing mean sensitivity scores and their error bars (SD) as a function of exposure time, perceptual modality and expertise across both experiments. A: results Experiment 1 (solely gauging vision). B: results Experiment 2 (gauging touch and the combination of touch and vision).

Figure 4-7 displays the results. All main effects are significant. As in both experiments separately, experts are better than the general public, $F(1,108)=79{,}10$, $p<0.0001$. Exposure time had an effect, $F(1,108)=12{,}57$, $p=0.0006$ as well as the perceptual modality used $F(2, 108)=34.53$, $p<0.0001$. There is a hint towards an interaction between exposure time and perceptual modality ($F(2,108)=3.01$, $p=0.0537$) such that the effect of exposure time was greater when solely touching than when solely seeing the banknote, while combining the two senses allowed for the strongest beneficial effect of increased exposure time.

4.5.4 Response biases

Relative to experts, the public had a different response bias, $F(1,108)=6.51$, $p=0.0121$. Participants of the general public had on average a lower β, meaning that they tended to declare banknotes more often as counterfeit, resulting in more hits and more false alarms. Exposure time modulated this response 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. Perceptual modality 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., induced a tendency to classify a banknote as authentic. As can be seen from Figure 4-8, almost all values for β are >1, which means that the participants employed on average a conservative criterion.

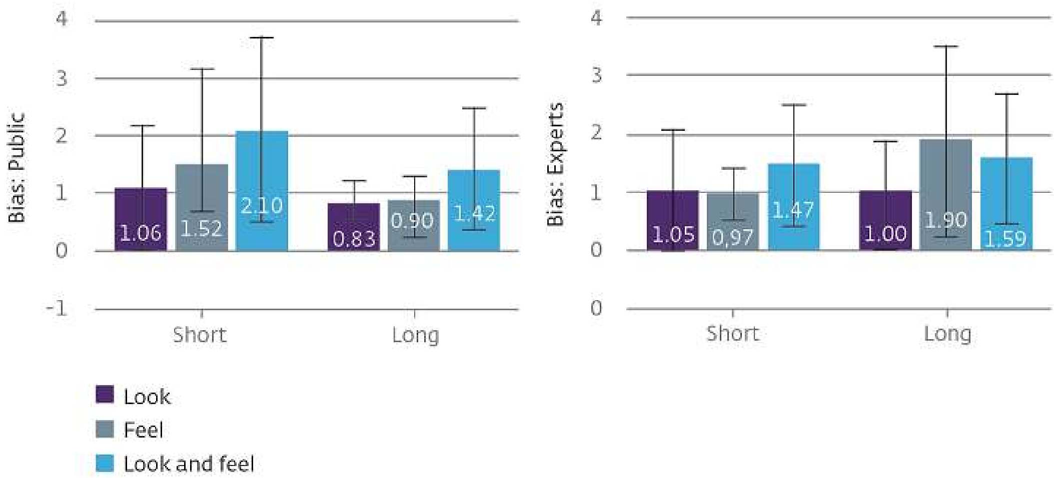

Figure 4-8. Average response biases and their error bars (SD) as a function of expertise and perceptual modality.

4.6 General Discussion

This study investigated the ability of participants (experts and non-experts, i.e. general public) to authenticate euro banknotes as a function of expertise, perceptual modality (sight and touch) and exposure duration. The results suggest that when solely seeing banknotes, participants from the public did well above chance even with an exposure duration of 500 ms and even when taking out the counterfeit that was most obviously fake. As such, interestingly, they did much better than what the participants themselves expected, as most participants had the idea that they were plainly guessing. Critically, looking longer at the banknotes (1,000 ms or 10 sec, until response) did not improve performance. This suggests that one's ability to detect counterfeits when solely relying on vision, is largely dependent on the first glance. In this respect a study by Raymond and Jones (2019) is relevant. This study suggested that a poor performance in authentication is especially obtained when people are not able to strategically fixate on security features that they know (for example the hologram). Perception of scene gist (or other global properties) that do not rely on precise eye fixation of security features are insufficient to support a satisfying banknote authentication. The results of the experts show a similar pattern regarding the necessary time as for the public: the performance of experts is much better but the performance does not increase much, if anything, with longer exposure durations. For the experts, it is as if a glimpse is enough to authenticate.

Reaction times indicated that it took longer to respond to a genuine banknote than to a counterfeit banknote. The reason that response times are longer for genuine banknotes might be that people look for evidence that the banknote is fake (a 'target present' trial) and thus will not stop looking for such a clue until the whole banknote is scanned, thus delaying the 'genuine' response (see e.g. Wolfe, 2012). Note that there was no difference in RTs between the public and experts. This particular result aligns with the response bias observed in our experiments. Participants were inclined to classify banknotes as counterfeits, which may have led them to continue looking for anomalies in the case of genuine banknotes.

Crucially, solely touching the banknote for a second yields the worst performance (Figure 4-7). The conception that vision is crucial in counterfeit detection is consistent with the findings of Klein et al. (2004) who tested cashiers handling Canadian banknotes. Klein et al. (2004) showed that performance was better with notes that could be seen but not touched, than vice versa. Hence, our study and that of Klein et al. speak univocally against the common notion that only feeling a banknote is enough to instantly know that a banknote is fake. Note however that moving over the surface was basically not possible in the one second touch condition. Movement of the finger is necessary to perceive the roughness of surfaces smaller than 30μ (Kappers & Bergmann Tiest, 2013). Hence, in future banknote design, central bankers should continue to address both senses with visual and tactile characteristics.

On average the public performed well above chance (a d-prime between 0.6 and 1.0) when solely looking or feeling, although worse than what could be called a 'reasonably good performance' marked by d' = 1.25; a criterion introduced by Raymond (2017). Note that in the 'feel and look' condition the general public scored well above this threshold of 1.25, as they had an averaged d-prime of about 1.8 in the short exposure condition and 2.4 in the long exposure condition

It is not surprising that the experts performed much better than the general public. Yet, what this indicates is that with more training and instruction, the performance of the general public could be much improved. Furthermore, the result that seeing and touching the physical banknotes results in much better performance than solely seeing the images on a screen, suggests that when developing new security features one should not only perform perception tests on a computer screen but instead have tests that also involve actual banknotes.

In closing, we are compelled to address some caveats. We tried to have the experimental conditions reflect normal handling of banknotes, but this was at best only an approximation. Seeing a banknote from a screen is different from looking at it in real life. For instance, so-called ‘tilt features’ such as optical variable ink cannot be detected when the note is statically displayed on a screen. Additionally, the way in which participants handled (i.e., touched) banknotes in the one-second condition in our study might, due to task demands, have been different from how they would (more casually) handle the banknote in real life. Indeed, it is generally assumed that in daily life people implicitly check banknotes for authenticity, most likely using Type 1 processing as defined by Kahneman (2011), while rarely engaging in Type 2 processing, entailing a deliberate check of whether or not banknote is fake. In contrast, our participants were likely to do so, as they were explicitly instructed on it.

What do these considerations imply for the generalizability of our results? It may well be that the observer’s ability to view the banknote at various angles would in real life induce a beneficial effect of exposure time when solely viewing the banknote—an effect that was absent in the present study. However, we see no reason to assume that the respective contribution of visual and haptic perception in real life would be much different from what we observed here. In Experiment 2, participants were indeed able to view the banknote at various angles, and this led to an increased beneficial effect of exposure time compared to when participants could only feel the banknote (Figure 4-7). It could further be argued that while participants most likely engaged in Type 2 processing (as opposed to the Type 1 processes thought to be invoked in most cash transactions), long exposure times in real life will most probably necessitate Type 2 processing as well; (indeed, the idea of quickly and superficially checking a banknote for 10 seconds would be fairly paradoxical).

Nonetheless, as potential directions for future research we may outline some ways in which to tease apart the respective contributions of visual and haptic perception in a more ecologically valid manner. In the conditions combining visual and haptic perception (our Experiment 2), one may collect video recordings from the participant’s first-person perspective. Subsequently, these recordings may be presented to participants in a separate experiment, so that they have the type of visual information that they would normally have, while the tactile information is left out. Differences in performance between the former and the latter setting could then be solely attributed to haptic perception.

In conclusion, whereas not much is gained beyond the first glance when solely relying on vision in the process of detecting counterfeit banknotes, the addition of touch allows one to accrue more evidence over time, leading to better counterfeit detection.

Annex 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 feel 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!

5

Enhancing counterfeit detection by guiding attention to security features and by manipulating target prevalence[20]

[20]This chapter corresponds to: van der Horst, F., Snell, J., & Theeuwes, J. (2021). Enhancing banknote authentication by guiding attention to security features and manipulating prevalence expectancy. Cognitive Research: Principles and Implications, 6(1), 1-10.

All banknotes have security features which are intended to help determine whether they are false or genuine. Typically, however, the general public has limited knowledge of where on a banknote these security features can be found. Here, we tested whether counterfeit detection can be improved with the help of salient elements, designed to guide bottom-up visuospatial attention. We also tested the influence of the participant's a priori level of trust in the authenticity of the banknote. In an online study (N=422), a demographically diverse panel of Dutch participants distinguished genuine banknotes from banknotes with one (left- or right-sided) counterfeited security feature. Either normal banknotes (without novel design elements) or banknotes that contained a salient element (a pink rectangular frame) were presented for 1s. To manipulate the participant's level of trust, trials were administered in three blocks, whereby at the start of each block, participants were instructed that either one third, one half, or two thirds of the upcoming banknotes were counterfeit (though the true ratio was always 1:1). We hypothesized (i) that in the presence of a salient element, counterfeits would be better detected when the location of the salient element aligned with the location of the counterfeited security feature – i.e., that it would act as an attentional cue; and (ii) that this effect would be stronger with lower trust. Our hypotheses were partly confirmed: counterfeit detection improved with 'valid cues' and decreasing trust, but the level of trust did not modulate the cueing effect. As the overall detection performance was rather poor, we replicated the study with a sample of university students (N=66), this time presenting stimuli until response. While indeed observing better overall performance, all other patterns were replicated.

Our results provide evidence that attention can be guided to enhance banknote authentication.

Because the general public has little knowledge on how to authenticate banknotes, this study investigated whether the introduction of novel, salient design elements would be helpful in detecting counterfeits. Also we tested the influence of trust in banknote authenticity on counterfeit detection. Two lessons can be learned here. Firstly, as lower trust yields better authentication accuracy, central bankers may see merit in raising awareness about the existence of counterfeit banknotes. Secondly, our findings provide a proof of concept for the idea that bottom-up saliency can be used to aid banknote authentication.

Keywords: attention, decision-making, gist, vision, touch, authentication, banknotes, counterfeits.

5.1 Introduction

Typically, people accept banknotes as change from another person or at a point-of-sale without consciously verifying authenticity (Klöne, Vrakking & Zondervan, 2019). Reasons for not checking authenticity are that counterfeit rates are extremely low, and that people trust the retailer (van der Horst, de Heij, Miedema & Van der Woude, 2017). Indeed, authentication may take place in a limited number of cases; for example, when the cash handler has encountered counterfeit banknotes before, or when the paper of a particular note feels somewhat unusual. Also, when one does not trust a particular transaction (e.g., an online purchase involving cash) one may check the authenticity of the banknote. A more practical constraint is that the general public has little knowledge of how to authenticate banknotes. On average, a person can mention two security features, but does not know what these features look like exactly, and where on a banknote these features may be found (van der Horst et al., 2017). For instance, 69% of the general public knows that a euro banknote contains a watermark, but only 6% knows what image the watermark depicts (De Nederlandsche Bank, 2021). The next most known security feature is the hologram foil, mentioned by 39% of the public. The emerald number can be recalled only by 2% of participants.

As a consequence, a good deal of counterfeited banknotes goes undetected. To illustrate, van der Horst, Eschelbach, Sieber & Miedema (2017) reported that around one in every five counterfeits is missed, in spite of the fact that participants were actively authenticating and were granted all the time they needed for this authentication task. It would not seem unreasonable to assume that the proportion of undetected counterfeits must be decidedly higher in everyday life, where cash handlers are not explicitly instructed to authenticate.

Yearly, the Eurosystem removes around 560 thousand counterfeits from circulation (out of a total of 24 billion banknotes; ECB annual report 2019). For an overview of the most prominent public security features, as indicated by the Nederlandsche Bank (DNB), see Figure 5-1.

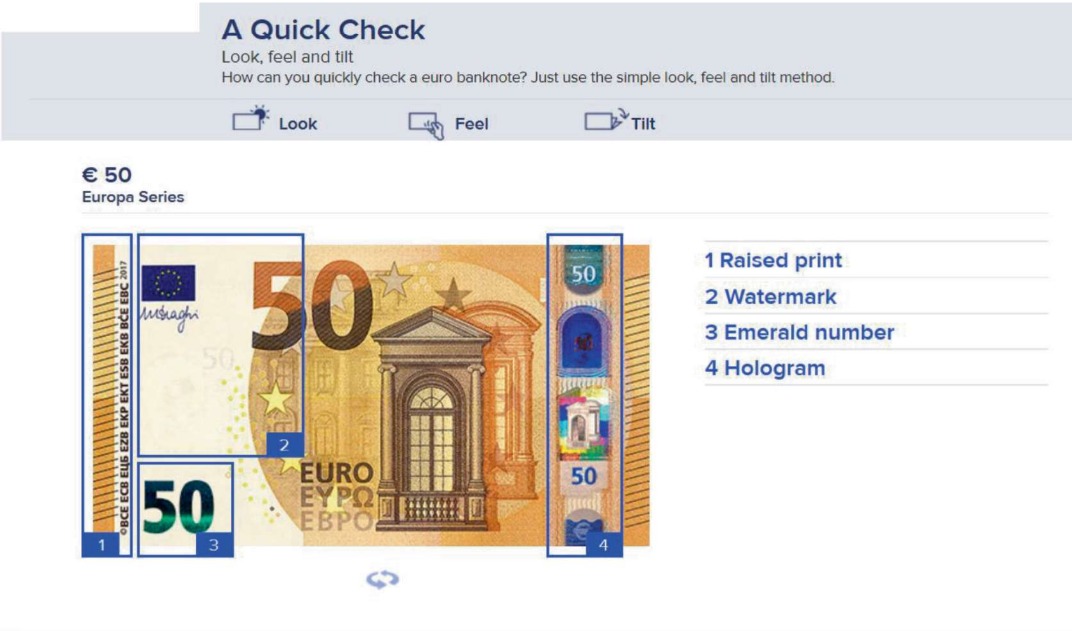

Figure 5-1. Instructional image on how to check the most prominent security features of a EUR 50 banknote quickly. Source: DNB website (www.dnb.nl/echtofvals).

Yet another reason for not checking the authenticity of a banknote may be that the authentication process would constitute a socially awkward or uncomfortable situation—all the more fuelled by the fact that aforementioned lack of knowledge would likely make the authentication process a long one. If cash handlers were able to authenticate banknotes more quickly and covertly, it may well be that fewer counterfeits would go unnoticed. Additionally, if banknotes were authenticated more easily, perpetrators may be less inclined to use counterfeit banknotes in the first place.

In short, members of the public are rarely inclined to check a banknote for its authenticity, but when they do, they lack the capability to do it properly. Here we investigated whether counterfeit detection can be improved with the addition of novel, salient visual elements, designed to guide visuospatial attention to critical locations. Additionally, we assessed the impact of one's a priori trust on attentional orienting.

Our hypotheses were guided by two distinct fields of study. The attention literature led us to reason that a counterfeited security feature should be detected more readily when attention is directed to the security feature's location. One way to ensure that attention is directed to a critical location is to introduce a visually salient element near the location of the security feature such that attention is captured towards the critical location in a bottom-up way (e.g., Theeuwes, 2010; Wolfe, Butcher, Lee, & Hyle, 2003). The hypothesized beneficial effect on counterfeit detection performance of having a salient element near a security feature, would be analogous to an attentional cueing effect (Posner, 1980). With respect to one's a priori of trust, we reasoned that lower levels of trust would increase overall performance (due to increased effort). We were largely agnostic with respect to interactions between trust and cue validity. On the one hand, one might argue that increased effort (induced by low trust) would cause stronger attentional orienting and consequently stronger capture by salient design elements. On the other hand, an increased contribution of top-down attention might reduce the strength of bottom-up attentional capture. Let us now turn to these attentional dynamics.

5.1.1 Attentional processes in counterfeit detection

Cash transactions at a point-of-sale are generally performed quickly and automatically (van der Horst & Matthijsen, 2013). People do not give themselves time, or might feel embarrassed when scrutinizing the banknote (de Heij, 2017).

To authenticate a banknote properly, a good strategy is to direct attention to the security features. Attentional orienting can proceed in a bottom-up and top-down manner. Bottom-up attention is usually deployed reflexively due to the characteristics of the scene and stimulus saliency (e.g. Theeuwes, De Vries, & Godijn, 2003), although the capture of attention can be prevented via an inhibitory mechanism that suppresses the salient stimulus (Luck, Gaspelin, Folk, Remington & Theeuwes, 2021). Top-down attention, which is thought to underly that inhibition, is usually deployed voluntarily in line with one's tasks and goals (Egeth & Yantis, 1997). However, top-down authentication of banknotes is likely hampered by the handler's aforementioned lack of knowledge.

It would therefore be ideal if security features were to capture attention in a rapid bottom-up manner (e.g. Theeuwes, 2019). It is worth noting that there has recently been a marked rise of simplified counterfeits without (mimicked) security features (Deutsche Bundesbank, 7-8-2020), suggesting that if attention were directed immediately and briefly to the relevant location on a banknote this could improve counterfeit detection. This underlines the importance of guiding banknote users' attention to security features.

It may come as no surprise that saliency is a well-known concept among developers of banknote security features. For instance, nano-optic display technology features deliver a sense of movement, 3D depth, and multiple colours. According to manufacturers these technologies enable a wide array of custom design options to both capture and hold the user's attention as they inspect and authenticate a banknote (16-11-2020, https://www.nanosecurity.ca/banknote-security/). However, to date there is no scientific dissemination about the effectiveness of security feature saliency. Furthermore, one must take into account the possibility that with increased saliency of one security feature, attention may increasingly be directed away from other security features. One challenge is thus to achieve optimally balanced saliency across features—a challenge enlarged by the fact that features differ from each other in terms of shape and size.

A potential solution—and the focus of this study—is to display a *single* type of salient element near each security feature. As such, the security features themselves can stay as they are, while the novel salient design element may become an established marker for areas worthy of inspection.

Although there is a lot of research suggesting that attention can be guided with the help of salient visual elements (e.g. Theeuwes, 2010), we must nonetheless be aware of one potential constraint. It is known that the most salient elements in a display typically receive attention first – irrespective of whether they are relevant or irrelevant (Wang & Theeuwes, 2020). Hence, if the salient element is at the same location as the security feature—as in the case of, say, a pink frame around the banknote's emerald number—attention would be at the right location; but would it predominantly be directed to the pink frame, or to the emerald number? In the former scenario, the salient element would be helpful in roughly guiding attention (e.g., attention would be oriented to the right quadrant of the banknote), whilst interfering at a more detailed level (e.g., attention would be focused on the pink frame rather than on what is in the frame).

We chose the colour pink (desaturated red) for the frame, because of its saliency. In an experiment conducted by Gelasca, Tomasic & Ebrahimini (2005) participants had to rank 12 colours in terms of saliency. The colours that had much more hits were red, yellow, green and pink. Those of lower saliency seemed to be light blue, maroon, violet and dark green. Also, in a colour experiment in which two groups searched for desaturated targets among saturated and white distractors, the conclusion was that the pink and peach targets have an advantage over the green, blue, and purple targets concerning reaction times (Kuzmova, Wolfe, Rich, Brown, Lindsey, & Reijnen, 2008).

5.1.2 The impact of trust

As noted earlier, we expect that persons who have high trust in the authenticity of banknotes, for example because they assume that the counterfeit rate is low, perform worse than persons who expect a higher counterfeit rate. This hypothesis is based on the 'prevalence-effect'. Observers tend to miss a disproportionate number of targets when these targets are rare (Wolfe & Van Wert, 2010). In everyday life, the prevalence of counterfeits is very low. The general public mentions this as an important reason for not authenticating (Klöne et al., 2019).

Lau and Huang (2010) found that the prevalence effect depends on past experience, not on future prospects. In their study, participants were told either that targets would be frequent (50%) or rare (10%), and both these instruction types were provided in settings where the true prevalence was either 50% or 10%; (hence, prevalence and *the expectancy thereof* were orthogonally manipulated). As it turned out, the error rate depended not on the instructions given but on the true target prevalence of the blocks. However, it might have been the case that participants simply did not believe the instructions (i.e., that expectancy was not successfully manipulated).

In fact, other research suggests that both target repetition and target expectancy play a role in the prevalence effect (Godwin, Menneer, Riggs, Taunton, Cave & Donnel, 2016). In the study of Godwin et al., one group of participants searched for low and high-prevalence targets of one particular colour throughout the experiment, while another group searched for one target colour on high-prevalence slides and a different target on low-prevalence slides. As such participants received differential levels of target repetition across the lower and higher-prevalence targets. An effect of prevalence emerged in both groups, although it was weaker in the single colour condition than it was in the alternating-colour condition, suggesting that both target repetition and target expectancy play a role in the prevalence effect.

Previous studies have shown that prevalence expectancy can simply be influenced by task instructions. For example, in their investigation of lesion detection on chest radiographs, Nocum, Brennan, Huang & Reed (2013) found that expectations of a higher abnormality-prevalence rate, as induced by instructions, impacted doctors' perceptual sensitivity and visual search patterns, even though observers received the same stimulus material.

In the current study, we manipulated the expectancy of prevalence, which was assumed to affect top-down attention, and manipulated the presence or absence of a salient element around security features, which was assumed to affect bottom-up attention. The manipulation of expectancy is particularly important as it is one of the underlying factors of the trust one has in the payment system. The rationale is that people who have low trust in the authenticity of banknotes expect that the counterfeit rate is relatively high are more likely to invest more effort in authentication and thereby, to enhance authentication (van der Horst, et al., 2020).

5.1.3 The present study

To summarize the above, typically the general public does not authenticate banknotes because they trust the banknote to be genuine and because they have insufficient explicit knowledge about which locations on the banknote inform its authenticity. Therefore, in this study, we examined whether salient elements around security features may help the public in authenticating a banknote at a quick glance. It is important to determine whether authenticating can be done rapidly because cash transactions typically occur within a very brief time frame (van der Horst, Snell & Theeuwes, 2020). We hypothesized that displaying a pink frame around a counterfeited security feature would lead to better counterfeit detection. This manipulation is to some extent analogous with the classic Posner exogenous cueing paradigm (Posner, 1980), in which targets are typically detected faster and more accurately when a cue is valid than when it is invalid.

Importantly, we did not instruct our participants on the existence and location of security features, as the general public is not trained either. Below it will be seen that overall detection scores were indeed not very high. However, our focus is not the performance per se, but the difference between having a salient element near to versus away from, the counterfeited feature, thought to operate as a valid versus invalid attentional cue, respectively. By directing the participants attention to a counterfeited feature, we expect to improve their ability to categorize the banknote as counterfeit.

5.2 Method

5.2.1 Participants

In order to have a representative sample of the general public in the Netherlands, we made use of the LISS panel (longitudinal Internet Studies for the Social Sciences) run by CentERdata at Tilburg University. This panel is representative of the general population in the Netherlands and comprises around 5,000 households in the Netherlands. We aimed for a net sample of 400 participants, but in total 451 participants participated in the experiment. The panellists were 16 years and older. They received a small monetary compensation (EUR 7.50, real money) for their expenses (internet use and time).

5.2.2 Design

The experiment followed a 3 x 3 x 4 within-subjects design, with the following factors: *Cue* (left, right, none) ; *Trust* (high, mid, and low, corresponding to low, mid, high counterfeit expectancy, respectively); *Authenticity* (counterfeit element left, counterfeit element right, genuine, genuine); genuine is mentioned twice to have the same number of genuine versus counterfeit trials.

5.2.3 Stimuli

The test set consisted of images of genuine euro banknotes that were taken out of circulation and visually altered (counterfeit) versions of the same banknotes. We created counterfeits by replacing a single genuine security feature by a cut-out of a counterfeited security feature. There were two types of counterfeited security features: the hologram (silvery stripe) that is positioned at the right side of the banknote and the emerald number that is positioned at the left side of the banknote, corresponding to the counterfeit element right and left conditions, respectively). The cut-outs were obtained from counterfeits taken out of circulation by De Nederlandsche Bank. We used cut-outs of simple ink-jet counterfeits instead of the ones printed with offset techniques, as these are the most prevalent. According to DNB's national counterfeit analysis centre, the counterfeited elements in our test set were of average mimicking quality, which means that a counterfeited element can be noticed visually by the average person when attention is directed to it.

Additionally, for all banknote stimuli we created versions with a salient pink rectangle framing either the left or right-sided security feature. Because the hypothesized effects of having a salient element near to or away from a counterfeited feature are interpreted as attentional cueing effects, versions of counterfeited notes with salient element at the same versus different location as the counterfeited feature represent the Valid Cue and

Invalid Cue conditions, respectively. We chose the colour pink because it is rated as a particularly salient color (e.g. Gelasca, Tomasic, & Ebrahimini, 2005; Kuzmova, Wolfe, Rich, Brown, Lindsey, & Reijnen, 2008).

We used both EUR 20 and EUR 50 banknotes (denomination not being considered an experimental factor). The complete stimulus set consisted of 24 images, i.e. 2 Authenticity (genuine/counterfeit) x 3 Cue (left/right/no cue) x 2 Security feature (hologram/emerald number) x 2 Denomination (EUR 20/50). Denominations EUR 20 and 50 were used because these are by far the most used *and* counterfeited ones (press release DNB, 22 January 2021). The denominations EUR 20 and EUR 50 were manipulated according to the same method described above. Figure 5-2 shows examples of manipulated banknotes.

Clearly, the proportion of genuine and counterfeit banknotes in the test set (1:1) is quite different from the probability of encountering a counterfeit in real life, which is roughly 0.003% (ECB, 2019). In addition, one's perceived likelihood that one will receive a counterfeit does not directly reflect real-world prevalence either. Instead, we would argue that counterfeit expectancy is a function of immediate context, and that the subjective biases that stem from this context are much more variable than real-world counterfeit prevalence. It is these variations in subjective prevalence expectancy that are studied here.

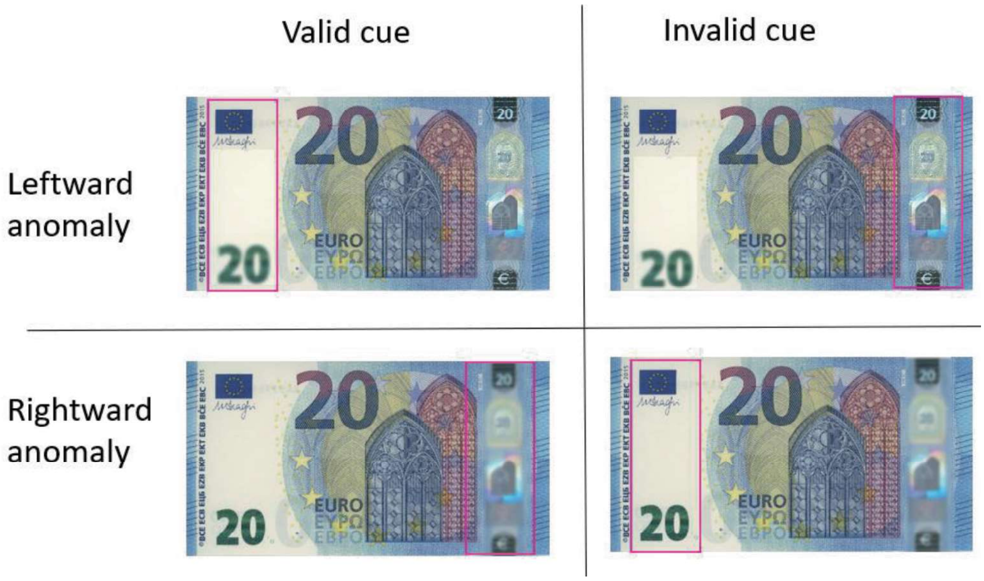

Figure 5-2. Examples of manipulated banknotes that are part of the test set. The banknotes on top contain a counterfeited emerald number: top-left with a pink cue around the counterfeited emerald number; top-right with the pink cue around a genuine hologram. At the bottom, banknotes with a counterfeited hologram: left-bottom a pink cue around the counterfeited hologram; right-bottom with a cue around a genuine emerald number. The two banknotes on the left are validly cued (the cue is located near the feature that is counterfeited). The two banknotes on the right are invalidly cued: the cue is near a genuine feature while the counterfeited feature is at the other side.

5.2.4 Procedure

Participants were invited to perform the test online on their own computers. For this reason, there was little control over the degrees of visual angle of our stimuli.

In the instructions participants were told that DNB wanted to test some design elements and that therefore a pink rectangle could be seen on the majority of banknotes. However, according to the instructions these new design elements would have no relation to whether the note was genuine or not. Next, participants were informed that banknotes would be presented for one second. They were instructed to authenticate the banknotes by typing a 'z' for genuine and '/' for counterfeit after the banknote was presented. They were instructed to respond as accurately as possible. They had a maximum of 4,000 ms to respond (after which the response would be considered an 'error'). Banknotes were presented centrally, albeit with minor jitter (ranging up to 40 pixels) in the banknote's x and ycoordinates, so as to prevent participants from developing oculomotor strategies. An overview of the trial procedure is shown in Figure 5-3. To get acquainted with the procedure, participants performed 12 practice trials that were not included in the data analyses.

The participants' trust in banknote genuineness was manipulated between blocks. All 24 images were presented three times, in three blocks (presented in random order for each participant). Every time before the start of a block, participants were informed on the expected ratio between genuine and counterfeits for the upcoming block: (i) two out of three, (ii) even, and (iii) one out of three. In reality, the genuine vs. counterfeit ratio was always 1:1.

At the end of the experiment, participants received feedback regarding their performance: a percentage correct was provided for all three blocks. Participants were invited to fill in a short survey for demographics, colour blindness and cash experience in working life (for the purpose of post-hoc analyses). The experiment took approximately 10 minutes.

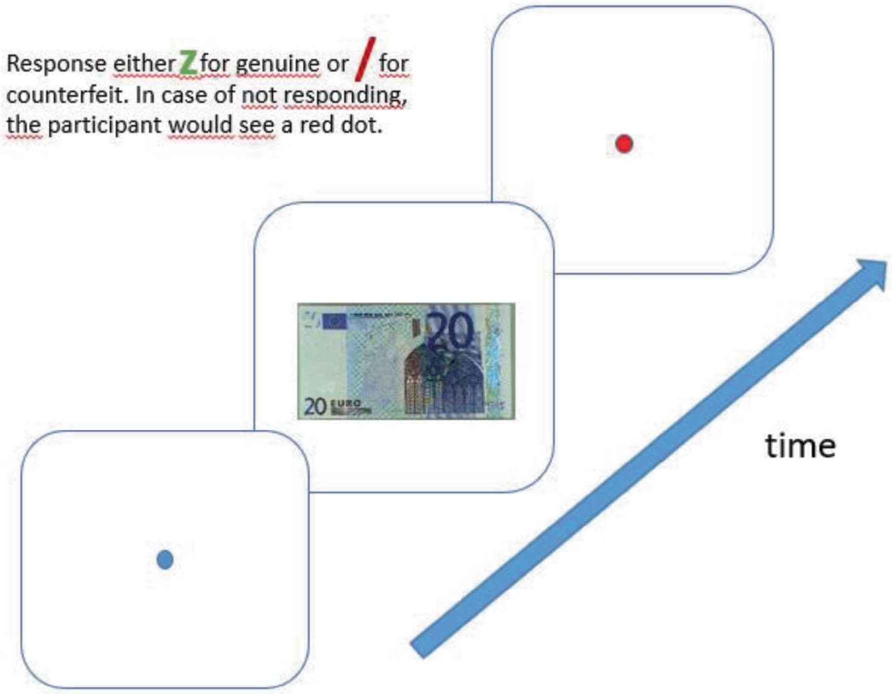

Figure 5-3. Example of a trial. Each trial started with a fixation dot in the centre, for 500 ms, followed by a banknote (either EUR 20 or EUR 50, either genuine or counterfeit, either with a cue or not). The display duration was 1,000 ms. The information regarding the ratio of counterfeits was varied between blocks. If participants failed to press a key within 4,000 ms from stimulus onset, the trial was logged as a time-out.

5.3 Results

All trials with a time-out were removed. In case this resulted in removing more than a third of a participant's trials, the data of this participant was removed altogether, as this indicates that the participant was not able to perform the task properly. In total, 29 participants were removed, constituting 9.1% of the data. The results of the remaining 422 participants were used.

To reiterate, the experiment included the following factors: Cue Validity (*valid* vs. *invalid cues*) and Trust (*low, mid-* and *high* levels of trust). These variables allowed us to rely, in part, on measures derived from Signal Detection Theory (SDT). The ability to discriminate genuine banknotes from manipulated banknotes is called sensitivity (d'), which can be estimated by deducting the z-transformed probability of false alarms (i.e., incorrectly classifying a genuine banknote as being counterfeit) from the z-transformed probability of hits. A d' score of 0 corresponds to a complete inability to distinguish genuine banknotes from counterfeits. According to Raymond (2017), a d’ of 1.25 represents decent sensitivity in banknote authentication. The maximum d’ score that can be obtained in this study is 3.92.

Importantly, while d’ can be calculated when inspecting main effects of Trust (i.e., irrespective of cueing condition), this is not the case when inspecting main effects of Cue Validity (i.e., irrespective of level of trust). This is because the cue valid and invalid conditions solely contain counterfeit banknote trials (indeed, consider that there is no such thing as a validly cued genuine banknote), and therefore one cannot conjure a false alarm rate required for the calculation of d’. Hence, in all analyses that involved the Cue Validity factor, we simply relied on accuracy (the SDT-equivalent of which would be the hit rate, retrieved from counterfeit banknote trials). Our central analysis (reported in Section 3.2) was thus a 2 x 3 repeated measures analysis of variance (ANOVA) with Cue Validity and Trust as factors, and accuracy as dependent variable.

We nonetheless also analyzed Trust in isolation (Section 3.1), as we could retrieve not only d’, but also the response bias (i.e. the extent to which one response is more likely to be given than another), or β, when inspecting this variable separately. The β measure, calculated by dividing the z-transformed probability of hits by the z-transformed probability of false alarms, provides an important verification of the effectiveness of our Trust manipulation. That is, if participants took the block instructions to heart, we expected them to have marked a larger portion of genuine banknotes as counterfeit upon being warned for a high counterfeit prevalence (although actual prevalence did not vary across conditions). At the same time, we may expect them to mark a low number of counterfeits as being genuine. Upon being warned for a low counterfeit prevalence, we would expect these patterns to be inversed. In short, if our Trust manipulation was indeed effective, we expect that β would be higher (i.e., more conservative) in the high-trust than in the low-trust condition.

5.3.1 Verifying the manipulation of Trust

Repeated measures ANOVAs were used to analyze main effects of Trust on d’ and β. Overall, sensitivity did not increase linearly with a decrease in Trust ($F(2,421)=2.131, p=.119$). We did, on the other hand, observe a numerical effect of Trust on β that approached significance: ($F(2,421)=2.437$, $p= .088$), with a more conservative response strategy in the high-trust than in the low-trust condition: i.e., lower levels of trust aided counterfeit detection, but, at the same time, caused a higher proportion of false alarms. From these results we conclude that the way in which we manipulated trust was effective.

5.3.2 Central analyses

A repeated measures ANOVA was run with Cue Validity and Trust as factors and Accuracy as dependent variable. In line with our hypotheses, valid cues led to better accuracy than invalid cues: $F(2,421)=4.969$, $p=.007$, $\eta 2p =.012$. Again, we also observed a main effect of Trust (F(2,421)=3.916,p=.020, η2p=.01), with better counterfeit detection at lower levels of trust; (however, given the absence of effects in d' and the reversed effect for genuine banknotes, as reported in Section 3.1, it can be argued that this particular effect reflects a shift in β, rather than a change in overall performance). Trust did not modulate the effect of Cue Validity: F(4,421)=.621,p=.648. Figure 5-4 shows the average scores for the nine conditions.

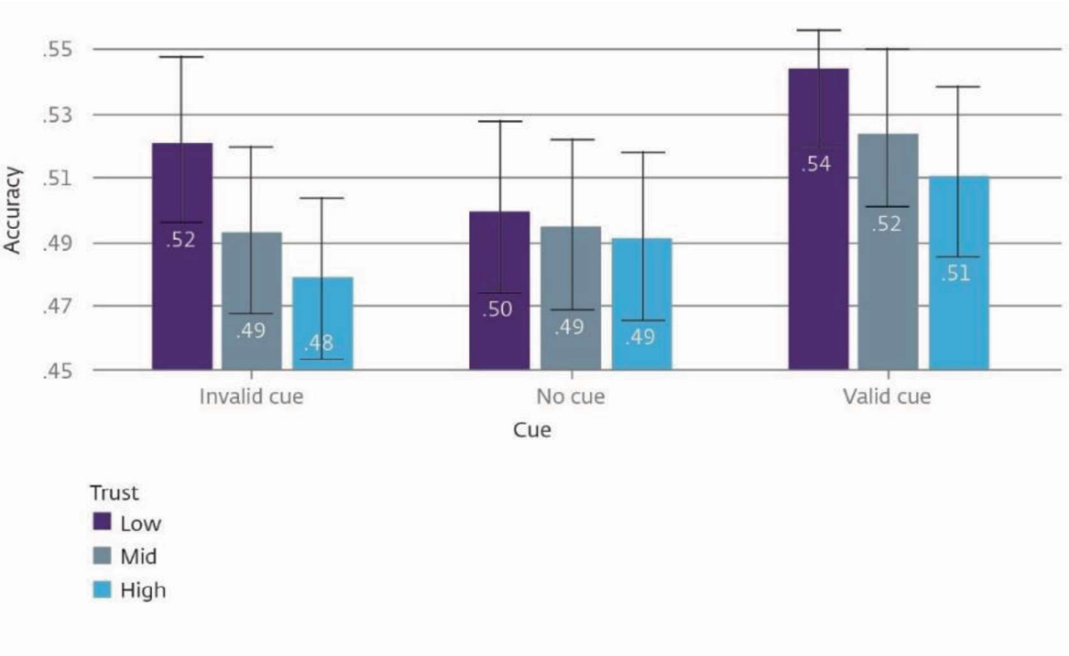

Figure 5-4. Average accuracy per level of trust (low, mid, high) and cueing condition. Both a low trust in the authenticity (i.e. a high expectancy on the number of counterfeits) and valid cueing led to better performance. Error bars depict 95% confidence intervals.

Evidently, overall authentication performance was quite poor in this population sample. In order to determine whether the task was too difficult, we calculated the average sensitivity scores in the no-cue condition, since this condition provides a baseline (without novel design elements) and as such can be compared to the study of van der Horst et al. (2020). We observed a sensitivity of d' = .386, which is indeed decidedly lower than the sensitivity d' = 1.05 observed in the study of van der Horst et al. (2020). Although overall sensitivity was quite low, it was significantly above chance-level (t(421)=11.274,p<=.001). It is also worth noting that the low sensitivity was unlikely to be driven by a lack of expertise: people who responded to have experience with cash in a professional setting did not perform differently from the others (t(420)=1.269,p=.205).

We reckon that recognizing a single fake element in an image of a banknote that is exposed for only one second might be difficult for non-trained members of the general public. Crucial in this regard is the fact that the salient design element, when acting as a valid cue, significantly improved performance.

We wanted to examine if the observed effect of cueing would also hold if the task was less difficult. For this reason, we decided to run the same experiment with a group of 66 psychology students and this time presenting the images of the banknotes until response. The results of this replication experiment are presented in the Appendix. Importantly, while the overall performance in this population sample was indeed better, we replicated all effects of interest (the bias of participants increased with a lower trust in the authenticity of banknotes: $F(2,66)=3.639, p=.029$). Just like the experiment with participants from the CenTErdata panel, we found main effects for accuracy per cueing validity ($F(2,66)=4.565, p=.012$), $\eta 2p = .07$ and trust ($F(2,66)=4.304, p=.015$), $\eta 2p = .06$ and no interaction between these factors: $F(4,66)=0.989, p=.414$. In addition trust affected sensitivity scores adversely: $F(2,66)=4.103, p=0.019$.

5.4 General Discussion

The goal of this study was to investigate whether salient design elements, intended to direct attention to the location of security features, would aid banknote authentication accuracy. In our experiments, pink frames around a counterfeited security feature were expected to act as a cue, akin to attentional cues in classic tasks such as Posner's cueing paradigm (1980). Similarly, a pink frame around a genuine security feature, when at the opposite side a counterfeited security feature was present, was expected to act as an invalid attentional cue. Participants were not instructed to react to these salient elements; they were only told that DNB wanted to test some new design elements. Across two experiments we confirmed our expectations. Banknotes with a salient element around the counterfeited feature location yielded better detection than banknotes with an 'invalid cue' (i.e., a salient element at a different location). These results provide a proof-of-concept that salient novel design elements can aid banknote authentication.

We also found that lower levels of trust aided counterfeit detection, but, at the same time, caused a higher proportion of false alarms (Section 3.1). It is worth considering that although high counterfeit detection rates are undoubtedly beneficial, effectuating these by means of lowering trust would imply extensive examination processes (i.e. more false alarms) and likely less smooth functioning of the cash payments system. Central banks may want to consider this particular finding when they issue press releases informing the public about counterfeit prevalence. In relation to this, Lau and Huang (2010) have argued that instructions alone might not be very effective in reducing error rates in real-life low-prevalence contexts, such as airport baggage screening or counterfeit banknote detection. Instead these authors have argued for randomly distributing 'pseudo-targets'. This would imply an artificial increase in prevalence, and the experience gained with such pseudo-targets would reduce the chance of missing actual targets. Applying this idea to the realm of banknote authentication, would not be realistic, as purposefully bringing counterfeits into circulation would, beyond legal constraints, lead to confusion to cash users and would adversely affect the trust in banknotes and the central bank.

The average sensitivity or d' in the no-cue (baseline) condition in the present experiment was .386. A d' of 0 corresponds to a complete inability to distinguish genuine banknotes from manipulated banknotes; and, according to Raymond (2017), a d' of 1.25 represents decent authentication sensitivity. Previous research (Van der Horst et al., 2020) showed a higher average sensitivity (d'=1.05) for the general public in a task similar to the present one (i.e., participants had to detect counterfeit banknotes that were presented for one second on a screen). There are however also important differences between the two experiments. Firstly, participants encountered novel design elements in the present study, which they ought to treat as being non-informative about the banknote's authenticity. Secondly, in the present study counterfeit banknotes contained only one counterfeit element, the emerald number or the hologram. Lastly, the counterfeit quality may have differed between the studies. These factors possibly made the distinction between genuine and counterfeit banknotes smaller than in the study of van der Horst et al. (2020).

In our replication experiment with psychology students (N=66) that saw the stimulus until response, overall performance was decidedly better (d' = 1.73 in the baseline condition). The pattern of positive effects on counterfeit detection by validly cueing and low trust was also found in this replication experiment.

The present findings demonstrate a possible role for bottom-up saliency to aid banknote authentication.

One potential caveat, however, is that attending to one security feature (helped by a salient element) may come at the cost of not attending to another, equally important security feature. Further tests of our hypotheses may involve comparing the authentication of banknotes without pink frame, against banknotes with multiple pink frames (i.e., one around each security feature). If our claims hold, then the pink rectangles should facilitate quicker serial processing of all relevant locations on the banknote, and thus better performance as compared to banknotes without pink rectangles.

Lastly, while saliency should help in finding the security features, what to do next - i.e., how to use these security features for successful authentication - remains a challenge. Further research on making the security features more intuitive may thus be beneficial for counterfeit detection.

In conclusion, the present findings suggest that salient design elements may aid counterfeit detection. This cueing effect is also shown for perceptual sensitivity measures such as accuracy and d' (Bashinski & Bacharach, 1980; Theeuwes & Van der Burg, 2007). Additionally, as low levels of trust positively impacted authentication, we posit that the general public would benefit from increased awareness about the existence of counterfeit banknotes.

Appendix

Replication experiment, presentation time increased

In line with our expectations, the 66 students, who were granted a longer presentation time, performed better than the panel. The average sensitivity for the no cue condition was 1.734, definitely higher than the sensitivity score for the CenTErdata panel of Dutch participants (0.386). This score is also considerably higher than a sensitivity score of 1.25, which is the norm that Raymond (2017) proposed for representing a reasonably good performance.

The influence of trust on the authenticity of banknotes was calculated with a GLM repeated measures. In this experiment higher trust influenced sensitivity scores negatively: F(2,66)=4.103,p=.019 (Figure 5-5).

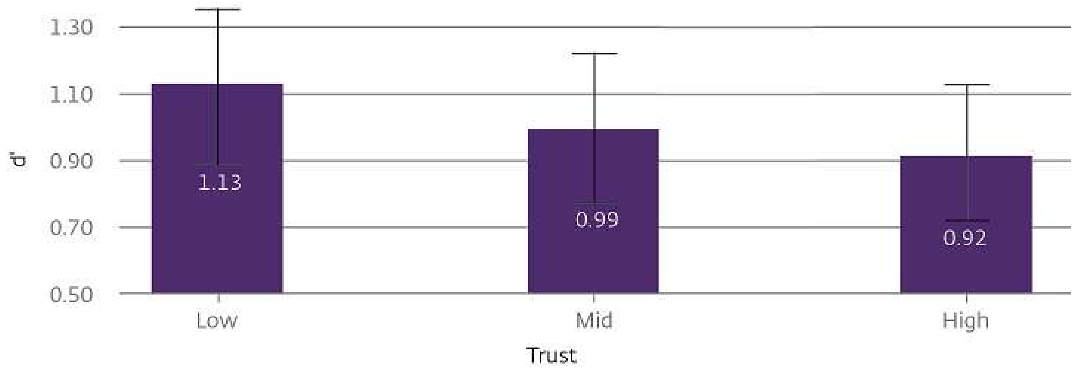

Figure 5-5. Average authentication sensitivity scores per condition of trust in the authenticity of a banknote (low, mid, high). Presentation time is until response. The sensitivity scores of participants significantly changed when the expectancy of the ratio of counterfeits was varied. Error bars depict 95% confidence intervals.

The bias of participants increased with a lower trust in the authenticity of banknotes: F(2,66)=3.639,p=.029. This means that when the participants have low trust and expect a high ratio of counterfeits the criterion is also high. Such a bias is called conservative, i.e. not willing to make that much false alarms and taking the chance of lower hits. Conversely, a low expectancy on the number of counterfeits leads to a more liberal criterion, i.e. that participants made both more hits and false alarms. See Figure 5-6.

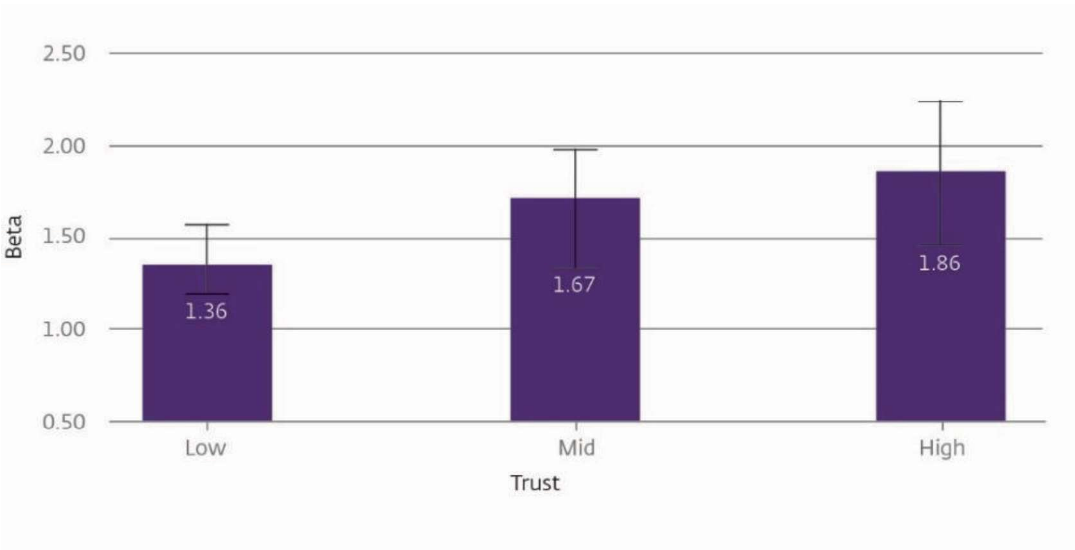

Figure 5-6. Average bias scores per level of trust in the authenticity of a banknote. When images were presented until response, a high trust has led to a more conservative bias, i.e. a lower tendency to declare a banknote a counterfeit. Error bars depict 95% confidence intervals.

Just like the experiment with participants from the CenTErdata panel, we found main effects for accuracy per cueing validity ($F(2,66)=4.565, p=.012$), $\eta 2p$ =.07 and trust ($F(2,66)=4.304, p=.015$), $\eta 2p$ =.06 and no interaction between these factors: $F(4,66)=0.989, p=.414$.

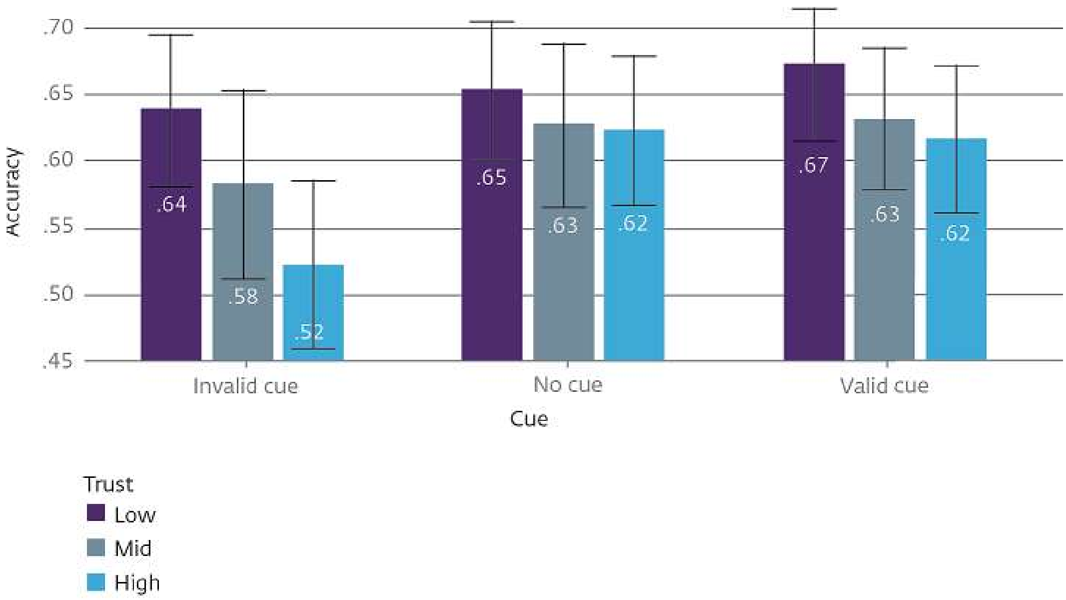

Figure 5-7. Average accuracy per level of trust (low, mid, high) and per valid or invalid cueing condition. Presentation time is until response. Both a low trust in the authenticity (i.e. a high expectancy on the number of counterfeits) and valid cueing led to better performance. Error bars depict 95% confidence intervals.

6

Conclusions

This thesis provides a framework for understanding the role of processes such as perception, judgement, decision-making and attention in counterfeit detection. We introduced a tentative dual processing Model for Accepting or Rejecting a Counterfeit in a cash transaction (MARC). Chapters 3, 4 and 5 provide some empirical data consistent with this model. The following conclusions can be drawn.

6.1 Dual processing model for acceptance of counterfeits

The model (MARC) provides an account of why people accept or reject a counterfeit. This model was conceived on the basis of insights from psychology, as well as studies regarding banknote authentication. If a cash transaction takes place under familiar, well known and safe circumstances, the banknote looks normal and the person has trust in the banking system, it is likely that the banknote will be accepted more or less automatically (Type 1 behaviour) without the involvement of much conscious effort. However, there may be a trigger overriding this automatic behaviour resulting in an effortful and conscious inspection of the banknote according to what has been labelled as Type 2 behaviour (Kahneman, 2011). According to MARC, reasons for this switch in processing may be found in the experiences of the individual with counterfeited money, the situation and the properties of the banknote.

As reviewed in the Introduction, the general public seldom checks banknotes because of a high trust in the authenticity of the banknotes. Furthermore, people have insufficient explicit knowledge about which locations on the banknote could inform its authenticity. Chapter 5 of this thesis showed that a lower trust in the authenticity of the banknotes, i.e. by manipulating prevalence expectancy, leads to better banknote authentication, but at the same time, a higher proportion of false alarms. The influence of trust on counterfeit detection is valuable information for central bankers, as they may see merit in raising awareness about the existence of counterfeit banknotes. At the same time, for a well-functioning cash payment system, a high detection rate is crucial, but a low false alarm rate is also key. Therefore, central bankers should weigh such communication against the possibility that people may lose some confidence in the money system if warnings are too emphatic.

We have also established, empirically, that both senses touch and vision are important for the authentication process (Chapter 4). But, as outlined in the Introduction, attention is the gateway to perception, and therefore it is important that the security features (irrespective of sensory modality) have some attention-grabbing properties. Generally, given the fact that counterfeits often go unnoticed, it could be argued that security features are currently lacking somewhat in saliency. In this light, the most important lesson from Chapter 5, is that attentional capture may be boosted by the addition of salient design elements (e.g., pink rectangles) around security features. Tactile information is also crucial as this information is processed automatically even when people have no intention to process this information (Wijntjes, 2009). Visual information seems to mostly impact the decision-making process during the first glance, whereas tactile information increasingly aids performance as it continues to be accrued over time (Chapter 4).

6.2 Future perspectives

The most important empirical lessons, as outlined in Section 6.1, are that decreased trust and increased saliency aid the authentication process. But from a more practical standpoint, one important question remains: *What is the perfect banknote*? Guided by our empirical findings (Chapters 3, 4 and 5) and theoretical considerations (Chapters 1 and 2), let us ponder tentative answers to this question in the present Section.

If security features would be self-explanatory, the need to rely on explicit knowledge would be reduced. An example might be a window in a banknote (as for example in Canadian banknotes). One does not need a manual to understand that the banknote can be authenticated just by looking through it. In order to achieve an optimal design, a security feature must fulfil multiple criteria simultaneously: it must provide confidence in the authentication process, it must attract attention and it must be easily recognized.

What security-feature design attributes lead to better authentication? Below, clues are provided based on literature regarding attention, on intuitive design for interfaces and on web designs. Moreover, information from interviews with banknote specialists and design specialists from security feature manufacturers is used. I propose the following characteristics of banknote security features that may lead to better authentication. It must be noted, however, that not all of these are supported by empirical evidence yet. Therefore, ideas for future testing will be provided.

6.2.1 Attention-guiding features

Chapter 5 of this thesis shows that counterfeit detection improves when introducing attention-guiding, and salient design elements. Generally, bottom-up salience can play a role in aiding banknote authentication, but this can take on a wide range of forms. Properties that could be included are colour contrast, movement, motion, orientation and size. But the banknote may also offer clues that aid top-down search such that it becomes clear what security feature to look for. An example might be a security feature in the form of a flickering flame positioned in a hearth of a wintery scene. The scene would guide attention towards the flame and the banknote handler might automatically understand that the note needs to be tilted to authenticate it.

Eye-tracking studies can support future research into the elements that attract attention during banknote evaluation. In 2013, DNB had Neurensics perform an eye-tracking study on the €5 banknote of the second series that had just been introduced at that time. The banknotes were shown on a computer screen to 25 participants, aged 18-39 years. Eye-tracking was done at 50 Hz. The heatmaps in Figure 6-1 show the average gaze time measured over 5 seconds. The longest gaze times are marked in red, followed by yellow and green. The newly introduced emerald number did not attract the eye, possibly because the banknote was shown on a screen, so the emerald number's movement effects were not apparent (Figure 6-1).

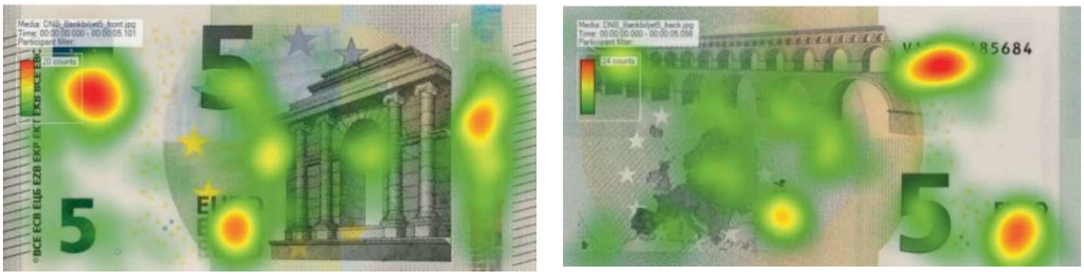

Figure 6-1. Eye-tracking study on the €5 banknote, performed by Neurensics for DNB in 2013. Left right is the back of the note (not published).

It is key to realize that it is not only important to notice the attention-guiding feature, but also the absence of it (in the case of a counterfeit), in case the counterfeiter did not succeed very well in mimicking the security feature (see e.g. Introduction Section 1.2.3).

6.2.2 Familiarity of features

When one is familiar with a search target, it is likely that one will find it faster. The watermark is a familiar target, as this feature has been used on many banknotes worldwide. A watermark is a recognizable image or pattern in paper that appears as various shades of light/dark when viewed by transmitted light, caused by thickness or density variations in the paper (Chahall, Kaur & Singh, 2014). The watermark is applied to the paper with special printing techniques. 69% of the Dutch public is aware of the watermark in euro banknotes (DNB, 2021). In general, people know that they have to hold the banknote up against the light to check the watermark. Another example of familiarity might be the use of clear typography and a clear colour usage in the design of banknote, like the design of 'Monopoly money' (Arnold, 2021).

6.2.3 Features in good proportion to banknote design

A security feature should be in good proportion to the rest of the design, which entails at least three things. Firstly, the feature should fit the theme of the banknote. For instance, the theme of the Norwegian series is the sea because the country is defined by a lengthy coastline and because of its ties with the ocean, from the Vikings to the fishing industry to modern-day oil drilling. On banknotes with such a theme, it makes sense to have the optical variable ink feature in the shape of a ship cable. On the right-hand side of the 100-krone banknote (Figure 6-2), one can see three segments of an anchor chain integrated into the paper. When you tilt the note, the chain appears to move (Norwegian Central Bank, 2021).

Figure 6-2. Example of a security feature that fits the theme of the banknote. Source: Norwegian Central Bank, 2021.

Secondly, the target-distractor relation has to be taken into account when designing the banknote, which means that the feature must not blend into the background, but has to pop-out to make it discoverable. Thirdly, guidance by scene properties is important, in the sense that attributes of the scene guide attention to areas likely to contain targets (Wolfe, 2017). This has to do with logic, semantics and constraint. In the scenery of a living room, people will look for flames in an open fire and not at the room's ceiling.

6.2.4 Features that provide feedback

The user of a banknote should get feedback confirming that the method of authentication is correct. For instance, when you hold a banknote against the light, you will immediately see if the banknote contains a watermark. In order to give feedback, the feature should incite to do something with the feature, like tilting it in the case of a hologram feature. Panksepp and Biven (2012) propose 'play' as one of the basic emotions necessary for living and learning. It is characterized as involving playful and light-hearted movements and laughter. To test this idea, one could use the same technique for a security feature (optical variable ink, for example) and create two designs, one playful (e.g., two children throwing a ball back and forth when the banknote is tilted) and one not playful (e.g., two children that merely change their stance when the banknote is tilted).

6.2.5 Attractive

The design of a banknote should provoke unintentional focusing of attention via attractive elements. An attractive design could tell a visual story and use visual cues and triggers to guide the user to key salient points on the banknote landscape. Because of its attractiveness, people will remember it more easily. They will look forward to using it and speak about the design with others. Emotional learning, for instance thanks to an attractive design, helps to store the information in memory better. Over time, memories of neutral stimuli decrease but memories of arousing stimuli remain the same or improve (e.g. Kleinsmith & Kaplan, 1963).

An attractive design might also be beneficial in phase 1 of MARC, the trust one has a priori in the authenticity of the banknote. This would be due to the so-called HALO effect, i.e. the tendency to judge a product (or person) positively based on one positive aspect ("what is beautiful, is also good-principle"). This phenomenon was first coined by Thorndike in 1920 when he described an experiment where he asked commanding officers in the military to evaluate a variety of qualities in their subordinate soldiers. Before the officers even communicated with their subordinates, Thorndike had the superiors rank them based on character traits. These characteristics included such things as leadership, physical appearance, intelligence, loyalty and dependability. Positive and negative opinions formed by the officers were based on unrelated traits that had to do with physical impressions. For example, a tall and attractive subordinate was perceived as being the most intelligent. He was also ranked as overall "better" than the others. Thorndike found that physical appearances are the most influential in determining our overall impressions of another person's character.

In terms of banknote design, the same principles may apply when adopting elements such as the children playing catch and throw (see the example in Section 6.2.4).

6.2.6 Clear (unambiguous) features

Currently, security features used on banknotes are rather complex and the average user is unsure of how to check them. Indeed, complexity is a double-edged sword: on the one hand, a complex security feature may be more difficult to copy by counterfeiters, but on the other hand, it may be more difficult for general users to authenticate complex, multi-dimensional features. Sometimes security features techniques are combined, which makes it more difficult to communicate to the public. A large see-through window is an example of a clear feature in the Bank of Scotland's five-pound note (Figure 6-3). If you can see through it, it is a good outcome of the security feature (yes). If not (no), it can lead to mistrust.

Figure 6-3. Example of a clear (unambiguous) security feature that incites a 'yes/no' decision about authenticity. Source: Bank of Scotland.

6.2.7 Concise naming

A lot of people do not know how to describe the features. They say things like: "a little shiny thing". Giving a feature an easy name helps people to recall it later. Establishing correspondence between verbal and non-verbal memory traces by assigning and learning meaningful labels, facilitates later retrieval (e.g., Meilinger, Schulte-Pelkum, Frankenstein, Hardiess, Laharnar, Mallot & Bülthoff, 2016). Place names corresponding to what can be seen at a location facilitate learning and may thus be considered when naming places and constructing wayfinding aids. In this light, the fact that current euro banknotes depict windows and doorways on the front side, not always recognized as such by the public, is not a good example of this characteristic. Culturally-driven elements, such as in the Norwegian example of Section 6.2.3, may allow more concise naming (e.g. "the ship").

6.3 Limitations

In closing, it is important to address a few limitations in the present work. A clear limitation is the fact that not all components of the model could be empirically verified within the scope of the thesis. For instance, regarding attitude, I tested the influence of trust in the authenticity of a banknote in counterfeit detection, but one could also think of individual differences in personality (for trustworthiness).

Additionally, situational factors may vary. Chapter 2 discusses a DNB study that looked into the influence of unsafe surroundings on cash usage. Chapter 3 provided evidence for an influence of the level of fitness of a national cash circulation. However, other aspects such as the time available for banknote authentication likely play a role too. Furthermore, I made some suggestions to create banknote designs that may promote authentication. Further research into these suggestions and their efficacy is recommended.

The participants in our empirical studies were asked to determine whether a banknote is counterfeit or not, which is quite unlike cash transactions in everyday life. In fact this request to our participants evoked most likely a conscious deliberate inspection of the banknote (Type 2 processing). It is important to notice that a recent study tried to circumvent this problem. In this study, conducted by Bank of Canada (Omrane 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 practice people focus more on cash handling than on authentication. It was found that this instruction led to the occasional detection of counterfeits. Not surprising counterfeit detection performance in this study was much lower than when participants had counterfeit detection as their main task (Omrane et al., 2018).

The criteria that we propose for intuitive security features are mostly based on (psychological and design) literature and discussions with experts in the field. This thesis does not provide evidence for the validity of all these criteria. It is recommended to test these criteria in future work. If proven successful, they might be part of an 'intuitivity scale' that can be developed in the future.

The last limitation that I would like to point out is the following. In this thesis, I have advocated that saliency helps in counterfeit detection. This will not come as a big surprise to anyone working in the field of security feature design. Saliency is important, which is why the industry produces glimmering foils, optical variable ink and so on. The limitation here, in short, is that the emphasis on the importance on saliency may be deemed to be not very novel.

However, it is nonetheless important to understand what will happen if such a feature is mimicked. Things can go two ways: either it is badly mimicked or it is deceptively mimicked. When a security feature is mimicked badly, then the banknote can easily be detected as a counterfeit as the absence of a salient feature is likely to be noticed. When the security feature is mimicked well, then the salience feature is present, and attention is guided to the feature, which promotes the accurate detection of counterfeits. Incorporating saliency seems to be optimal either way.

6.4 Contribution

I have prepared this thesis to provide better insight into why people accept counterfeits based on a dual processing model with four phases of a banknote acceptance. Furthermore, I provide suggestions to improve banknote design, thus contributing to ensuring the public's trust in banknotes in general. This will help central banking authorities in their task of promoting a safe and reliable payment system and eventually will benefit the public at large because of fewer counterfeit losses.

The proposed model contains various points at which an individual might be triggered to authenticate a banknote deliberately. Central banks have little influence on the triggers. However, banknote design can be improved by introducing even more intuitive features and people can be influenced to adopt the attitude that it pays to be somewhat alert at all times.

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Summary

Banknotes have been counterfeited ever since their introduction. Today, around 350,000 counterfeit euro banknotes are retrieved on an annual basis from circulation worldwide. These counterfeits are seldom of good mimicking quality. Nevertheless, they have been used in a transaction, implying that at some point (or several points) someone has encountered a financial loss. To central banks it remains somewhat of a puzzle that people accept counterfeited banknotes, as it is generally believed by central banks that security features of banknotes can be verified easily.

In this thesis, I propose a Model for Accepting or Rejecting a Counterfeit (MARC) that is based on a dual processing theory in which it is assumed there are two different processes that people may use when making decisions. The central viewpoint is that rapid autonomous processes (Type 1) are assumed to yield default responses unless intervened upon by distinctive higher-order reasoning processes (Type 2). Regarding MARC, this means that the default response is an automatic acceptance of a counterfeit (Type 1), as research shows that people generally accept banknotes without consciously verifying their authenticity. This default process transitions into a deliberate authentication process (Type 2) due to a lack of confidence in the cash system, unusual environmental circumstances, or a poor quality of the banknote. Depending on the abilities of the assessor and the characteristics of the security features of a genuine banknote, this authentication process may or may not lead to detecting the counterfeit. Suggestions for the design of better security features are discussed, including attention-guiding features that fit the design of a banknote.

This thesis comprises experimental studies that provide some support for MARC, with a focus on the factors prompting (or increasing) Type 2 processing and, consequently, the cognitive factors determining success rates. All these studies have made use of signal detection theory (SDT) measures to gauge participants' counterfeit detection performance. The first study refers to one of the situational factors. Specifically, the research question was whether the quality of (genuine) banknotes in circulation (the environment) affects counterfeit detection. The study led to the conclusion that the cleanliness of banknotes in circulation helps counterfeit detection. However, the high detection rates in the clean sets of the samples were accompanied by a large number of false alarms. A clean circulation does not seem to contribute to authentication sensitivity. The second study refers to the respective roles of vision and touch, as well as exposure duration. Visual information mostly impacts the decision-making process during the first glance, whereas tactile information increasingly aids performance as it continues to be accrued over time. It could also be deducted that with more training and instruction, the performance of the general public could be much improved. A third study focused on the hypothesized benefit of (1) adding salient design elements to a banknote, and 2) manipulating trust.

In summary, this thesis provides insight into why people accept counterfeits, using knowledge of attention, perception and decision-making processes. An overarching goal is to contribute to maintaining the trust of the public in banknotes in general. This will help central banking authorities in their task to promote a safe and reliable payment system and eventually will help the public at large through reduced counterfeit losses.

Nederlandstalige samenvatting

Bankbiljetten worden al sinds hun intrede in de economie nagemaakt. Tegenwoordig worden jaarlijks wereldwijd 350.000 valse eurobiljetten uit de bankbiljettenomloop gehaald. Vergeleken met de 28 miljard echte eurobiljetten die wereldwijd in circulatie zijn, is de kans op het aantreffen van een vals exemplaar klein. Aangezien vervalsingen niets waard zijn, vormt elk biljet een verliespost ter grootte van de waarde die erop stond. Eurobiljetten zijn met behulp van echtheidskenmerken goed beschermd tegen namaak. Volgens centrale banken is het eenvoudig om een biljet op echtheid te controleren. Daarom lijkt het niet logisch dat mensen soms valse eurobiljetten aannemen, vooral als deze biljetten niet goed zijn nagemaakt.

In dit proefschrift stel ik een 'Model for Accepting or Rejecting Counterfeits' (MARC) voor dat inzicht biedt in het aannemen of afwijzen van een vervalsing. Dit model is gebaseerd op dual-process theorieën, waarbij wordt aangenomen dat er twee verschillende processen zijn die mensen gebruiken om te komen tot hun beslissingen. Snelle autonome processen (Type 1) worden verondersteld standaardreacties op te leveren, tenzij ingegrepen wordt door meer analytische denkprocessen (Type 2). Volgens MARC betekent dit dat de standaardreactie een automatische aanname van een vervalsing (Type 1) is, aangezien uit onderzoek blijkt dat mensen over het algemeen bankbiljetten accepteren zonder bewust op echtheid te controleren. Dit standaardproces gaat over op een doelbewust authenticatieproces (Type 2) dat veroorzaakt wordt door drie redenen: (i) een gebrek aan vertrouwen in de echtheid van eurobiljetten, (ii) een ongebruikelijke omgeving waarin de contante transactie plaatsvindt, of (iii) een slechte kwaliteit van het bankbiljet. Afhankelijk van de capaciteiten van de beoordelaar en de eigenschappen van de echtheidskenmerken van een echt bankbiljet, kan dit authenticatieproces wel of niet leiden tot het herkennen van valse bankbiljetten. Het publiek heeft beperkte kennis van de echtheidskenmerken en waar deze kenmerken zich op het bankbiljet bevinden. Daarom bevat deze thesis ook suggesties voor het ontwerp van betere echtheidskenmerken, waaronder aandachtstrekkende kenmerken die passen bij het ontwerp van een bankbiljet.

Dit proefschrift bevat experimentele studies die enige ondersteuning bieden voor het idee van MARC, met een focus op de factoren die Type 2 verwerking stimuleren (of verhogen) en, als gevolg hiervan, de cognitieve factoren die succesvolle herkenning bepalen. Al deze onderzoeken hebben gebruik gemaakt van signaaldetectietheorie (SDT) om de prestaties van het ontdekken van vals geld door deelnemers te meten. De eerste studie verwijst naar één van de situationele factoren. Concreet was de onderzoeksvraag of de kwaliteit van (echte) bankbiljetten in omloop van invloed is op de detectie van valse biljetten. Uit het onderzoek is geconcludeerd dat de netheid van echte bankbiljetten in omloop helpt bij het opsporen van vals geld. De hoge ontdekkingspercentages in de schone test sets gingen echter gepaard met een groot aantal valse alarmen. Een schone circulatie lijkt niet bij te dragen aan het goed onderscheid kunnen maken tussen echt en vals. De tweede studie verwijst naar de rollen van de zintuigen zicht en gevoel, en naar de effecten van de tijd dat een biljet waarneembaar is. Visuele informatie heeft op het eerste gezicht vooral invloed op het onmiddellijke besluitvormingsproces, terwijl tactiele informatie de prestaties verbetert naarmate er meer tijd verstrijkt. Uit het onderzoek kan ook worden afgeleid dat met meer training de prestaties van het publiek aanzienlijk kunnen worden verbeterd. Een derde studie richt zich op het voordeel van (1) het toevoegen van opvallende ontwerpelementen aan een bankbiljet en 2) het manipuleren van vertrouwen c.q. de verwachting over het aantal valse biljetten.

Samenvattend geeft dit proefschrift inzicht in waarom mensen vervalsingen accepteren, met behulp van kennis over aandacht, perceptie en beslissingsprocessen. Er worden daarnaast suggesties gegeven voor een beter ontwerp van echtheidskenmerken. Als men eurobiljetten controleert en verdachte biljetten weigert aan te nemen, kan voorkomen worden dat criminelen vrijuit kunnen betalen met valse biljetten en dat de ontvangende partij blijft zitten met financiële schade. Dit draagt bij aan de taak van de centrale bank om een veilig en betrouwbaar betalingssysteem te bevorderen.

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Frank van der Horst

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About the author

Frank van der Horst was born in Amsterdam, the Netherlands, on April 17, 1959. Frank started working at De Nederlandsche Bank in 1978. While working full-time at DNB, Frank started a Master's program in Social Psychology at the University of Amsterdam in 1985, receiving his degree in 1994. Since 2010, Frank van der Horst has been working partly as a scientific researcher and partly as a senior policy advisor at the Cash Policy Department of De Nederlandsche Bank. Frank is primarily engaged in the following topics: public perception research, counterfeit banknotes, the Dutch cash cycle and banknote stock management. Frank is a member of several Eurosystem committees, including the Issue Expert Group and the Eurosystem Research Network on Cash.

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