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Banknote design for the visually impaired

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Abstract

The visually impaired are divided in three subgroups: colour-blind, partially sighted and blind people. Their first needs are useful denomination features rather than security features, as they help them in determining a banknote's value. This study provides a historical overview of banknote design features for the visually impaired, especially as applied in the former Dutch guilder notes. Furthermore, it looks into the methodology of banknote tests for the colour-blind, showing images of how the colour-blind experience the euro banknotes.
Two features are needed for every subgroup of the visually impaired to establish the banknote's value; one is not reliable. These two features are dedicated firstly to the relevant user group, but will also be used by others, including people with normal vision.

Colour-blind

- Create a colour scheme for all denominations suitable for both the colour-blind and normal sighted people. Realize maximum colour differences between successive denominations.
- The individual banknotes should be monochrome and vivid. Avoid pastel tints (added white), avoid grey scale colours like olive green and brown (added black).

Partially sighted

- Increase the denomination figure to a height of 22 mm. Use numerals both on the front and on the reverse. Keep numerals on the same location. Create a clear contrast between the numbers and the homogenous background. Print one denomination figure as a dark number on a light background and the other vice versa: 'light on dark'.
- Create clear 'silhouettes' on the front, e.g. by different shapes of the main image.

Blind

- Create a large and increasing length difference between the low denominations, i.e. 7 mm, 8 mm and 9 mm. High denominations do not really need a length difference (but if possible: yes). The height of all denominations can be the same, preferable between 65 - 75 mm. A uniform height is the world wide trend; banknotes fit better in wallets and are more efficient to produce, distribute and sort.
- Provide all denominations with a coded tactile structure, using dots and lines variants on alternating denominations. Use also the short and long edges of the notes. Make use of the new digital engraving techniques with a higher relief and sharper slopes.
- If foil print is part of the production of the banknote, use this smooth element also as an orientation device to assist the blind in recognizing the front (from the reverse) and the top (from the bottom) of the banknote.

The synthesis of these design requirements leads to new design concepts, some of which are shown in illustrations. Embarking on that road for the euro banknotes would lead to a 'euro social' design policy that goes beyond the symbolic image of a non existing window or bridge.

Keywords: applied design, currency, payment systems, cash money, banknotes, banknote design, visually impaired, colour-blind, partially sighted, blind.

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1 Introduction

The design of the denomination features for the visually impaired is the subject of this paper. The basic question is: How should a central bank instruct the graphic designer today to make banknotes suitable for the colour-blind, partially sighted and blind? The answer to this question follows from the development phases of 'applied design': information, analysis, problem definition, planning and drafting. Necessary steps before the design phase of 'giving shape'.

Vision barrier

Worldwide, coins and banknotes are used by everybody except the very young. However, not all users are seeing the same when checking out a banknote (Figure 1). To a colour-blind person, for example, the colours of a 50 euro banknote appear more brownish but still sharp, while a partially sighted person might see nothing but a brown hue. A totally blind person will not see anything at all.

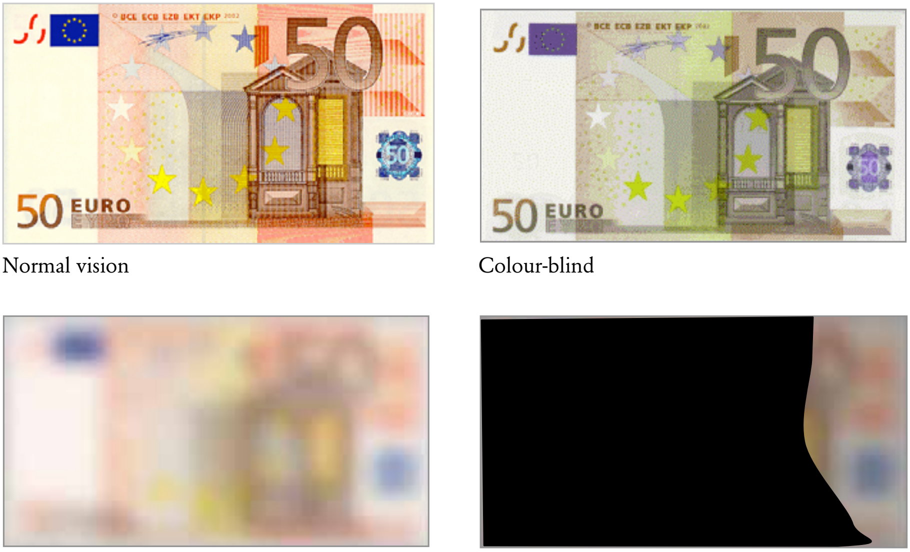
Visually impaired are people having a barrier in their eye sight. To overcome this blockade denomination features in the banknotes have to be designed in an 'exaggerated' way. This is why people with normal vision will also benefit from banknotes optimised for the visually impaired. Banknote-issuing authorities must keep the visually impaired in mind when commissioning new banknote designs, and make sure that the denomination features are given most prominence.

What is known from the literature?

Analytical studies on currency design and on banknote features for the visually impaired are rare. As far as known, the first formal study on the needs for the visually impaired was conducted in 1983 in the USA by the Bureau of Engraving and Printing (BEP), part of the Department of Treasury [15]. This report cites unpublished earlier studies (1976, 1980) on methods for easing the recognition of a banknote's denomination [82].

In 1986 the Nederlandsche Bank (DNB) commissioned a large-scale experiment to investigate the effectiveness of the tactile marks for the blind on the NLG notes in circulation. The main conclusion from this study with 40 blind participants was that the marks were not very helpful. Especially on used notes the marks proved barely tangible. As a result, almost half of the blind participants said they never

Figure 1



Normal vision

Colour-blind

Partially sighted

Blind

Four different visual perceptions of a 50 euro banknote.

made use of the marks. These research results were made public and were the first to appear regarding this particular issue [24, 26, 29]. See also Appendix 6.

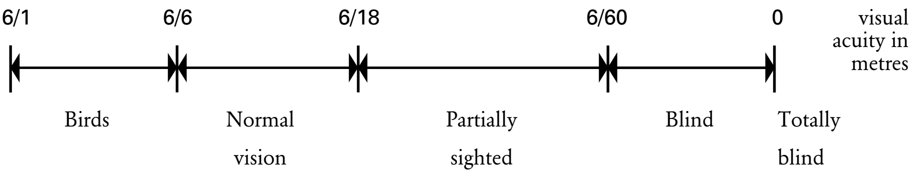
The 1995 *report of the National Research Council (NRC)*

Today, the 1995 report 'Currency features for the visually impaired' by the National Research Council (NRC) is still the most extensive public study on the topic [37]. The work was done in the USA on request of the BEP. The occasion was the redesign of the US banknotes, for which the same NRC had just finished a report for the security features to be used in the next generation of US dollar notes [35]. The colour-blind were not covered by this study since 'no relevant documents could be found' and 'more study is needed' and, on page 65, 'Highly directed, psychophysical/empirical technical work should be undertaken as a high priority effort that addresses questions regarding optimum dimensions, optical contrast, location, colours, physical size, etc., to make recognising and denominating U.S. banknotes easy, convenient, and inconspicuous for visually disabled individuals.'

One of the major conclusions of the NRC was that banknote dimensions are not a reliable denomination check. The NRC also reported in this context that 'the committee found no technical literature evaluating the effectiveness of denomination differentiation by size.'

A few detailed studies were published after this general NRC report, e.g. a study on the tactile features in the Canadian banknotes by Ledermann in 2002 [56] and

Figure 2



Schematic representation of the visual acuity of birds, people with normal vision, partially sighted, blind and totally blind. Not on scale.

tactile features produced with the new intaglio plate making techniques by Dinse in 2005 [67, 99].

In 2006, De Heij produced a study of different banknote dimensions, including requirements for the blind [74]. An overview of currency features for the visually impaired was published by Williams and Anderson in 2007 [82], and in 2008, De Heij presented a paper on requirements for tactile structures on banknotes [86].

Definition of 'partially sighted' and 'blind' by their visual acuity

'Partially sighted' and 'blind' can be defined by clearness of vision, or: visual acuity (Figure 2).

Visual acuity is expressed relative to normal vision, which, in the metric system, is set at 6/6 m. If someone has a visual acuity of 6/60 m, this means that, at a distance of 6 metres from a given object, the same details can been seen as a person with normal eyesight would at a distance of 60 metres from that object. In terms of foot as unit, visual acuity is expressed relative to 20/20.

Besides the metric and the foot systems, other systems are available to express visual acuity (decimal system, LogMar system). Visual acuity is often measured on the basis of the sizes of the letters viewed on a Snellen chart or the sizes of other symbols, such as tumbling letters like the C or E in various orientations.

It is possible to have vision superior to 6/6 m. The maximum acuity of the human eye without visual aids such as binoculars is generally thought to be around 6/3 m or 20/10 in foot. Some birds, such as hawks, are believed to have acuity around 6/0.7 m or 20/2 in foot. Obviously, their vision is much better than human eyesight.

How many visually impaired?

Statistics on visually impaired are usually in numbers instead of percentages. The colour-blind are often not part of these statistics, although they are the largest group of visually impaired. The reason for this is that colour-blindness is experienced as a mild disability. Accounting for around 4.2 % of the population, the colour-blind are a much larger group than the poor-sighted or the blind.

According to the World Health Organization (WHO) there are worldwide more than 161 million people visually impaired; among them 124 million have low

Table 1

Visually impaired people			Male	Male and female	Female
1.	Colour-blind		8 %		0.4 %
2.	Low vision	Europe		1.46 %	
		Americas		1.53 %	
		Western Pacific		1.89 %	
		South East Asia		2.10 %	
		Easter Mediterranean		2.47 %	
		Africa		2.97 %	
3.	Blind	Europe		0.31 %	
		Americas		0.28 %	
		Western Pacific		0.54 %	
		South East Asia		0.73 %	
		Easter Mediterranean		0.80 %	
		Africa		1.01 %	

Overview of the different groups of visually impaired people.
The male colour-blind are clearly the largest group. Low vision and blind are based on the global estimate of visual impairment by WHO regions in 2002.

vision and 37 million are blind (year 2002). More than 90 % of the world's visually impaired live in low- and middle income countries. Table 1 shows that there are large differences between the different regions; Africa (3.98 %) clearly has more visually impaired than Europe (1.77 %) [62]. This last figure is used by the European Central Bank (ECB) reporting that close to 2 % of the population of the European Union have a significant visual disability [42, 49]. For the Netherlands this figure is 1.82 % (in 2005) [77].

2 A history of trial and error

The development of denomination features for the visually impaired is characterised by trial and error. Central banks and designers do not seem to have a model from which they are working on further developments. Detailed histories of these features and related measures are provided in Chapters 3, 4 and 5. As the former NLG notes figure prominently in these accounts, these Chapters – and their Appendices – in fact also describe the history of NLG banknotes. Features for the visually impaired have proved a complex element of banknote design. It seems that only continuous research can guarantee sustained improvement of the features for the category of banknote stakeholders under consideration.

NLG banknotes

De Nederlandsche Bank has always conducted research to address the needs of the visually impaired. In 1966, it was the first to come up with clear numerals and in 1971, it was the first to introduce marks for the blind. The innovative banknote series in question also featured 6 mm length increments between denominations, while the note height was uniform (76 mm) with a view to the introduction of mechanical sorting. This note was also innovative because of the use of large numerals against a clear background. Because of its monochrome colour setting and its vivid colours this design was already suitable for use by the colour-blind, even if it was not intentionally designed that way. Serving the visually impaired remarkably well, these NLG notes were highly appreciated. The NRC committee praised the 1987 report [29] on research conducted by DNB in cooperation with 40 blind persons [37].

The right thing to do

Some central banks are more thorough than others in developing banknote features for the visually impaired; the most active being the Bank of Canada. 'It is the right thing to do' they argue, referring to the Canadian Human Rights Act (1977), which provides for barrier-free access to currency by all Canadians, and the lobby of the visually impaired.

People should be able to participate in everyday cash transactions, just as much as they are free to use public transport, is the opinion of the European Blind Union (EBU). Any (new) currency system should be accessible to most visually impaired without the need of adaptation or special aids [38]. In 1996, DNB's president

Figure 3

First banknote with
- Marks for the blind
- Vivid colour

The innovative NLG 10/Frans Hals issued in 1971, first of a new series. Design: R.D.E. Oxenaar.

Duisenberg fully endorsed this opinion when he said: 'The blind and the partially sighted should be able to participate independently in payments.' [39]. Such statement is in line with the Dutch policy in other fields, like public transport.

Are central banks really doing their best for the visually impaired?
Usually, the national organisations promoting the interests of the visually impaired are consulted when new banknote series are to be designed. Most central banks feel the need to do something for the visually impaired. To underline their positive attitude in the design of their new series, the Swiss national bank representatives consulted representatives of the Swiss blind union in a completely dark room. Both teams had the same experience!
The reply from the visually impaired can be unpredictable, depending on the active knowledge of the representatives. Five blind persons representing their organisation may declare themselves in favour of tactile marks on the new note. But does this mean that the marks will really be used?
Meanwhile the central bank proudly reports on milestones regarding marks for the blind or related measures. For example, in a brochure published in 2002, the ECB writes: 'The European Blind Union was consulted extensively during the design phase of the euro banknotes to ensure that the needs of blind and partially sighted people were adequately catered for.' [54]. However, judging by comments from

Figure 4

User Requirements	⇨	Design Requirements	⇨	Design

From user requirements to design requirements and to the design process phases. User, customer and stakeholder requirements are synonyms. Design and functional requirements are also similar.

the Dutch visually impaired, the euro banknotes are not yet fully satisfactory (see Chapter 3, 4 and 5).

Visually impaired dissatisfied with USD banknotes

The visually impaired could even force a central bank to adjust its banknote designs. A case in point is a US federal judge's ruling in 2006 that the US Treasury Department was violating the law by failing to design currency that is readily distinguishable for the blind and visually impaired. The case had been instituted by the American Council for the Blind. The Rehabilitation Act's guarantee of 'meaningful access' was found to be violated as a blind person could not accurately identify paper money without assistance [80].

In May 2008, the US Court of Appeals ordered that the US currency should be redesigned to make it easier for the blind to differentiate between denominations, leaving it up to government officials to determine the best solution. It cannot be explained why US currency should be any different from the vast majority of other currency systems, so was the judgement.

Visually impaired are no product developers

Organisations for the visually impaired neither have access to knowledge about banknote production techniques, nor to new banknote designs. They are also unable to provide banknote printing specifications. The best they can do is drawing up a list of requirements from a user's point of view. User requirements are needed to arrive at design requirements and, subsequently, at a good banknote design for the visually impaired (Figure 4).

User requirements are often abstract and do not tell how to the design problem should be solved. User requirements – in this case for banknotes – can be seen as higher levels in the target-means diagram, while design requirements are found on the lower levels [86].

These requirements can be derived from research reports and user comments. So far no design-relevant cultural differences from one country to another between the blind, poor sighted or colour-blind have been identified. Therefore, it would seem safe to conclude that the needs of the visually impaired are the same worldwide.

User requirements – general

User requirements like 'easy to use' or 'user friendly' should be further analysed and broken down into more operationally defined, problem-setting requirements:

- is assistance needed?
- is an additional tool needed?
- can it be done discretely and is the denominating time less than 3 seconds?

The most important success factor seems to be the time needed to detect and recognize a feature. There is no such research available on the time needed to denominate a banknote, except in the case of the notes from the Bank of Canada (see Appendix 6). It seems that a detection time of 3 seconds is acceptable (since a security feature may take up to 2 seconds [73, 81]).

User requirements by the visually impaired

The 1995 NRC report contained a list of user requirements based on suggestions regularly made by the American Council of the Blind to the BEP. That same year also the user requirements of the EBU were made public [38].

The needs of the colour-blind are not (yet) covered by organisations for the visually impaired like the EBU or the Dutch Viziris organisation. In the Netherlands, the small private organisation Blind Color advocates that products be accommodated to the needs of the colour-blind (see Chapter 3).

Quantitative user requirement

Coding six banknote denominations by length is likely to result in some errors of absolute judgement, e.g. by mixing up the denominations 10 and 20. The accuracy can be improved by using one more independent variable, for example a printed texture. Up today a single denomination feature is found not 100 % reliable. That is why both the NRC and EBU require at least two different denominating features for both the blind and the partially sighted. Diameter and edge profile are two such independent variables to discriminate different coins [37, 38].

Fewer denominations

Fewer denominations reduce the probability of errors being made. This EBU recommendation opts for a minimum number of different denominations of notes. The euro has 7 denominations, while other major currencies have less. The USD has 5 denominations (excluding the USD 2) and the Japanese Yen has just 4, same as the British pound. With only around 1.2 % of the total volume of euro banknotes (ultimo 2008), it is clear that the euro 200 would be the first denomination to be removed from the euro series. It is also the least known denomination (61 % spontaneous awareness in NL in 2009) and just one out of five Dutch people has had a euro 200 note in their hands in 2008 [81, 102]. Such a measure will not help the blind much though, since this note is not part of the change.

Practical test

One of the most important user requirements would seem to be the practical test. The EBU recommends that the new coin or banknote is tested using a range of people with different degrees of disability before final decisions are made on any design. Such a test – if not several tests – should be made part of the project planning for a new banknote design.

Orientation feature

A point made several times by the NRC is that the banknotes should be provided with an orientation feature to help the blind and partially sighted feed banknotes properly oriented into a vending machine. Also the EBU recommends providing a orientation marks on the notes by way of 'boldly visible markings, which could be the denomination figures'. People with normal vision would benefit equally from such 'orientation feature'. In 2005, DNB conducted a design study for such features for people with normal vision [74, 81].

Can banknote designers be of help?

Yes, banknote designers can help! First the designer should be aware of the latest user and design requirements as well as of the criticism regarding the previous banknotes. In line with the stakeholders' policy, central banks should be knowledgeable on the issue and inform the designer accordingly. Secondly, priority should be given to the needs of the visually impaired throughout the design process. It is often said that what is good for the visually impaired, is also good for people with good sight. This design approach will lead to new banknote concepts. Such proposals may inspire both designers and their project managers.

Central banks should take the lead

Although there is some knowledge collected into this paper about the visually impaired, clearly more research is needed. In addition to offering its latest banknote design for comments to organisations for the visually impaired, a central bank should initiate separate research projects to increase the usefulness of currency features for the visually impaired. The central bank should take the lead in doing pro-active research with these stakeholders. Projects executed in consultation with the colour-blind, partially sighted and blind will be the most effective.

Study on US-dollar (July 2009)

In July 2009 the so called ARINC-report became available. The Bureau of Engraving and Printing initiated this study to examine various aspects of the use of US currency by blind and visually impaired [106]. At that moment in time the first printing proof of this Occasional Study was already made. As a consequence the content of the ARINC-report is not used in this DNB-study.

3 Colour-blind

Central banks have only recently become aware of how people with defective colour vision experience banknote designs. This stakeholder, around 13 million people in the euro area, was therefore overlooked by the developers of the first series of euro banknotes. The colour-blind were – as far as known – first mentioned in a discussion document of the Bank of England in 1980. 'Because of the number of different categories of colour-blindness, there is no simple solution to the problem' was their conclusion at that time [8].

With the introduction of the TNO colour-blindness simulator around 1997, it became possible for people with normal vision to see what the colour-blind see [43]. The first test TNO conducted with banknotes using this simulator was for the Bank of Israel in 1997 [44].

Just a few days after the introduction of the euro notes in 2002, striking pictures appeared in one of the major newspapers in The Netherlands showing how the colour-blind perceived the new euro notes (see Figure 5). DNB contacted the author, Mr. Meinard Noothoven van Goor, and promised to lobby for better banknote design. This commitment was followed up in 2005 with a first colour-blindness evaluation test on new euro banknote designs [68], and a second one in 2008 [87]. These tests visualized how the average colour-blind person would experience the new designs.

The focus of this Chapter is: Which banknote denomination features will be most beneficial for the colour-blind? The colour-blind will also profit from features developed for the partially sighted and/or the blind, but these features are not described here. Large numerals, for example, are mentioned in Chapter 4 which covers first of all the needs of the partially sighted.

Requirements
Using the recently obtained knowledge as a lead, today, the following considerations should be taken into account concerning the colour-blind:
- Colour scheme of banknote series,
- Monochrome banknote colour,
- Vivid banknote colour.

Figure 5

Euro series as seen by normal vision and by the colour-blind (deuteranopes, colour-blind for 'green-red'). Picture colour-blind: Blind Color, 2002 [51, 53].

These topics are addressed in sections 3.2, 3.3 and 3.4. First colour-blindness needs to be described.

3.1 Colour-blindness, a historical overview

The term colour-blindness is in fact a misnomer, since complete colour-blindness or monochromacy is rare: 99.9 % of the colour-blind are only partially colour-blind. However, this terminology is well-established. The clinical term is 'defective' or 'deficient' colour vision. Monochromats are truly colour-blind and are only able to discern shades of black, grey and white. Active colour vision is no longer possible, then, resulting in colour-blindness in the true sense.
The ability to identify a colour is inextricably bound up with light. The eye absorbs the incoming light in three different photo pigments. These light sensitive pigments are contained in cone-shaped photoreceptors spectrally tuned to the short-, middle- and long-wave region of the spectrum, which are predominantly seen as blue, green and red. At low light levels the rods take over from the cones. This is also the case when a normal person wants to pay with cash in a dark taxi, a dark restaurant or at an outdoor market in wintertime. In such situations with not enough light there is not much difference between the colour perception by normal vision and by the colour-blind. Both will use the large numerals instead of colour determination.

'Red-green' colour-blind
There are 8 classes of defective colour vision (Table 2). The majority of the colour-blind (75%) have three photo pigments – just as people with normal vision – one of which does not function properly. Of this group, more than 80 % have irregularities of the green photo pigment (deuteranomalous) and the remainder have deviations of the red photo pigment (protanomalous). The second group of colour-blind are also identified by their green and red photo pigments. In this case of dichromacy people miss one of these photo pigments completely. Please note, the simulated images in this paper are for this group, the deuteranopes, i.e. those without green pigments (although the deuteranomalous are the largest group).

What causes 'red-green' colour-blindness?
The genes for the red and green colour receptors are located on the X chromosome, of which men have only one and women have two. A colour-blind male will transmit the ineffective gene to all his daughters, who will be carriers but remain unaffected. A carrier woman has a fifty percent chance of passing on the deviant gene to her male offspring. Therefore, genetic red-green colour-blindness affects men much more often than women. The sons of an affected male will not inherit the trait from him, since they only receive his Y chromosome and not his (defective) X chromosome.

Table 2

Type of deficiency	Characteristics	Incidence (%)	
		Man	Woman
Anomalous trichromacy	*Three photo pigments, one anomalous*	**5.9**	**0.38**
Protanomaly	Anomalous red pigment	1.0	0.03
Deuteranomaly	Anomalous green pigment	4.9	0.35
Tritanomaly	Anomalous blue pigment	unknown	unknown
Dichromacy	*Two photo pigments*	**2.1**	**0.03**
Protanope	Red pigment missing	1.0	0.01
Deuteranope	Green pigment missing	1.1	0.01
Tritanope	Blue pigment missing	0.01	0.01
Monochromacy	*One photo pigment*	**0.003**	**0.002**
Typical achromatopsy	Perception with rods only	0.003	0.002
Atypical achromatopsy	Perception with one type of cone only	rare	rare
Total		**8.0**	**0.4**

Survey of the various classes of defective colour vision and their percentage of incidence [59].

Females are 'red-green' colour-blind only if both their X chromosomes are defective with a similar deficiency. So, the daughters of a colour-blind woman can be only colour-blind if their father is colour-blind as well.

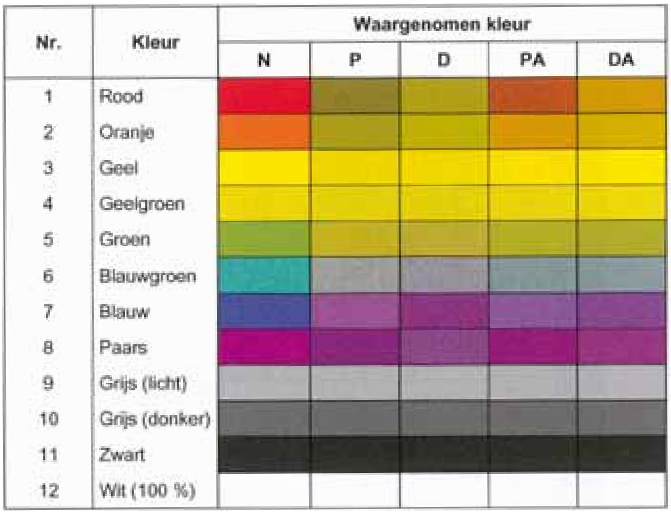
Blue-yellow colour-blind

The colour-blind people in whom the blue pigment is missing (tritanopes) are mentioned just for completeness sake. The incidence of people with anomalous blue pigment is unknown, but their numbers are very small and therefore negligibly low. This deficiency is not sex-linked, but equally distributed among males and females.

Blind Color

Colour-blind people often keep it quiet that they have difficulties seeing all colours. They experience difficulties in daily life and there are many examples. Just to mention a few: colour coded medicines, traffic lights and pale-red coloured bicycle lanes. Also vegetables and fruit are often problematic; the brown spots on overripe vegetables might not be seen. Computer games are using many colours. Today such games like Warcraft often have an option for colour-blind settings.

Table 3



Nr.	Kleur	Waargenomen kleur				
		N	P	D	PA	DA
1	Rood					
2	Oranje					
3	Geel					
4	Geelgroen					
5	Groen					
6	Blauwgroen					
7	Blauw					
8	Paars					
9	Grijs (licht)					
10	Grijs (donker)					
11	Zwart					
12	Wit (100 %)					

Reproduction of the perception of 12 colours by individuals with normal vision (N) and with different types of colour-blindness: protanopes (P), deuteranopes (D), protanomalous (PA) and deurteranomalous (DA). Picture taken from the (draft) standard NPR 7022 [72].

Promoting awareness in society and industry of the problems faced by the colour-blind is done by the Dutch organisation Blind Color. Where possible, they indicate and demonstrate how those problems can be overcome. Blind Color was founded after his retirement by Mr. Meinard Noothoven van Goor, a Dutch engineer by education and colour-blind.

Working on normalisation, the ISO/NPR 7022 guideline

One of the recent successes of Blind Color is the formulation of the (draft) standard 'Nederlandse Praktijk Richtlijn 7022' or in short NPR 7022, issued as a draft norm by the Netherlands Standardization Institute [72]. It is expected that after formalizing the draft, the standard will become an European ISO Standard. NPR 7022 deals with the functional use of colour, specifically directed at colour vision disorders. The standard helps to prevent mistakes and accidents as a consequence of colour-blindness. Manufacturers, designers and other users of this standard will have to create or adapt their products so that they can be dealt with by the colour-blind. The document includes a table – Table 3 in this paper – with colours as seen with normal vision and as seen by the colour-blind. This tool enabled unambiguous identification of 12 colours with optimal properties when combined by the colour-blind. Such change in colour perception can also be checked today with the 'Color Blindness Converter' issued in 2007 by Sikkens (part of AKZO Nobel Coatings International BV) and Blind Color.

Banknote difficulties
If this converter or Table 3 would have been known in the 1990ths it might have prevented central banks of issuing suboptimal banknote designs. The euro banknotes design was made in 1996 and the designers were unaware of the perception by the colour-blind. The red 10 and the blue 20 euro are perceived quite similar by the colour-blind, as is shown in Figure 5. Also the 50, 100 and 200 are quite similar to them.
And the Swiss banknotes might have been different too. The red CHF 20 note and the green CHF 50 note are rather difficult to discern for persons suffering from specific forms of colour-blindness. 'If one looks at the colour spectrum, the colour scheme of the current series is not completely satisfactory.' reported the Swiss central bank in 2005 [66].

Take care with colour switching security features
The colours selected for colour-changing public security features should also be selected with more attention for the colour-blind. DNB received a complaint that security features based on colour changing effects, like the colour changing numeral in the euro 50, cannot be discerned by the colour-blind [73]. The colour of the numerals on high euro denominations changes from purple to olive green or brown, depending on the viewing angle (Figure 6). Many colour-blind will not be able to discern this change.
Central banks should avoid that the colour-blind are less able to authenticate bank notes than the fully sighted population. Banknote designs which are overly dependent on colour shifting elements for its security features should be avoided.

Assessment of euro banknotes
When the euro banknotes were introduced in January 2002, Van Goor published the earlier mentioned article including the pictures of the simulated euro banknotes. These transformations were made by Dr. Jan Walraven, the inventor of TNO's

Figure 6

Colour-changing numeral on EUR 50 (or OVI, Optical Variable Ink). The colour change is from purple to olive green or brown is difficult to distinguish for the average colour-blind individual.

colour-blindness simulator. Blind Color offers both the use of the colour-blindness simulator and the expertise of Dr. Jan Walraven.
As mentioned in this Chapter's introduction, after contacting Blind Color, DNB suggested to the ECB to asses a next generation of euro banknotes on its usability for the colour-blind. The first test was performed on three newly developed euro banknotes, called the 2-year project ('emergency banknotes' 20, 50 and 100 euro) [68]. The second colour-blindness test was done for a euro 50 note redesign in 2008 [87].

DoCol method
Banknotes are multi-coloured and not monochrome. For colour measurements the multi-coloured banknote needs to be transformed into one single colour. The method developed and used is called the 'DoCol-method', short for Dominant Colour method. Of the various methods used to determine this DoCol, three were explored (see Appendix 1).

3.2 Colour scheme for banknote series

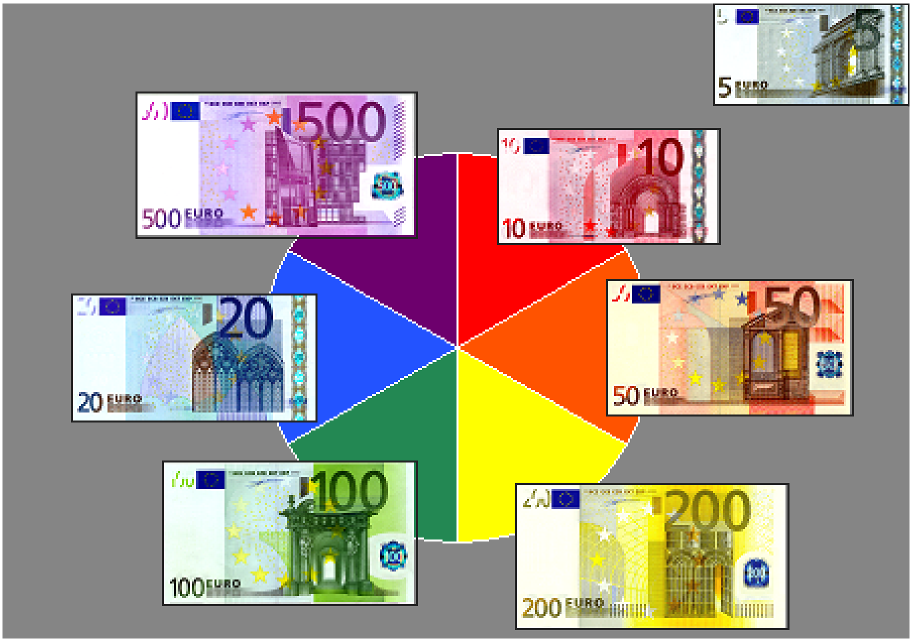
The first design step towards optimising banknotes for the colour-blind is to construct a colour scheme for the banknote series, suitable for both normal vision and the colour-blind.

Colour scheme for banknotes
The introduction of a completely new series offers the possibility to construct a new, optimised colour wheel including all denominations. This was e.g the case in Kyrgyzstan in 1992, when a completely new series of Som-notes was prepared. Kyrgyzstan was a former republic of the Sovjet Union, which became independent in 1991. The colours of this KGS series are derived from the colour wheel proposed by De Heij [34].

Colour scheme for euro
The scheme developed for Kyrgyzstan is based on the secondary colour circle, first described by Isaac Newton, but worked out further for designers by Johannes Itten, who was a teacher attached to the famous Bauhaus. Denominations that have one or more digits in common, like 10 and 100, should not be contiguous in the colour wheel. Also consecutive denominations like 20 and 50 should not be next to each other in the colour wheel. These principles are described in 'The design methodology of Dutch banknotes' [48] and were also used for the euro banknotes (Figure 7).

Primary printing colours
The primary printing colours blue, yellow and magenta or red are reserved for the notes that are used the most, i.e. the notes that are used as change in cash transactions and for supplying Automatic Teller Machines (ATMs). Since the human eye

Figure 7



The colour scheme of the euro banknotes based on the 1995 proposal by De Heij (DNB).
In the original proposal, the euro 50 note was yellow and the 200 orange. Since the colour wheel allows only 6 denominations, the seventh colour was chosen to be grey, just as the background in the colour circle of Johannes Itten. Being considered the first to be a coin, it was most logical to attribute grey to the 5 euro banknote.
One day the colour scheme might have to be changed, because of inflation. The 5 euro banknote will become a coin. Around 2040, a EUR 1,000 euro banknote might have to be added [81]. What will be its dominant colour? Picture by author.

is most sensitive to green, this secondary (printing) colour is well chosen for the 100, the (fourth) colour needed. The other secondary colours, orange and purple, are reserved for the higher denominations; purple for the most dignified note, i.e. the highest denomination.

Switching the 50 *and* 200

In the original euro banknotes colour scheme, yellow was earmarked for the euro 50 and orange for the 200 banknote. In 1996 this was not accepted because a yellow note would not be easy to print. This statement could not be confirmed by DNB since there were several yellowish coloured banknotes – low denominations – like in Belgium (BEF 200), Switzerland (CHF 10) and, of course, DNB's own bright orange/yellow NLG 50/Sunflower. To have the euro 50 in yellow would have been better for people with normal vision, although not that much for the colour-blind. They perceive the 50, 100 and 200 all as a yellowish-green colour (see Figure 5). For them it would be better to switch the 100 and 500.

When banknotes are circulated they become dirty. Also from this point of view yellow is a defendable colour, since the colour of soil seems to be yellowish [89].

3.3 Monochrome banknote colour

To accommodate the colour-blind, banknotes should be monochrome rather than polychrome. An example of a monochrome and a polychrome banknote is given in Figure 8.
Banknotes do not need to be totally monochrome, but the subordinate colours should leave the dominating colour untouched. This implies that a banknote's dominant colour is its most important design parameter. People should be able to tell this colour immediately from a banknote at a distance of around 3 meters. Banknote colour is also the most important design parameter for people having normal vision, as was concluded in several other investigations [e.g. 90, 102].

Balance monochromacy with some other colours
A banknote in a single, clear vivid colour might be relatively easy to counterfeit. Here the designer must strike a balance between two strategies. On the one hand secure colours should be brought into the note design, while on the other hand, these added colours should prevent the public from associating the multi-coloured note with a single colour and, hence, value.

Figure 8

Monochrome banknote

Polychrome banknote

Example of a monochrome and a polychrome banknote.
Left: NLG 10/Zeeland woman (The Netherlands, issued in 1925). Design J. Visser.
Right: RUB 100/Lenin (Russian Federation, issued 1991). After some hesitation about half the people might say brown (because of portrait) and the others opt for the central green area and the green numerals on the right.

3.4 **Vivid banknote colour**

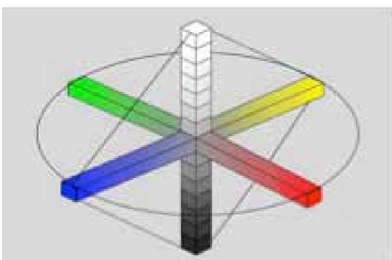
Older banknote designs are often monochrome as the colour-blind require, but did not have the vivid colours. A bright colourful design is needed and unsaturated colours should be avoided. The terms vivid, bright and saturated are all used for expressing the same colour parameter and are explained below.

Colour parameters
There are different systems to describe colour. One of them, the colour wheel has already been presented. If white and black are added to the colour circle a colour space is created as indicated in Figure 9. When white is added to a vivid colour it becomes a pastel tint and transforms from a saturated colour to an unsaturated colour. This phenomenon of colour saturation is explained by the perceptual colour space. The colours in perceptual colour space are ordered along three axes. One axis represents the colour pair blue-yellow and another axis the colour pair red-green, comparable to the North-South versus East-West axes of a compass. A third axis is the achromatic or black-white axis, passing perpendicularly through the centre of the colour circle. The closer colours are located to this central axis, the less colourful (less saturated) they are. Going upwards or downwards makes a colour lighter or darker.

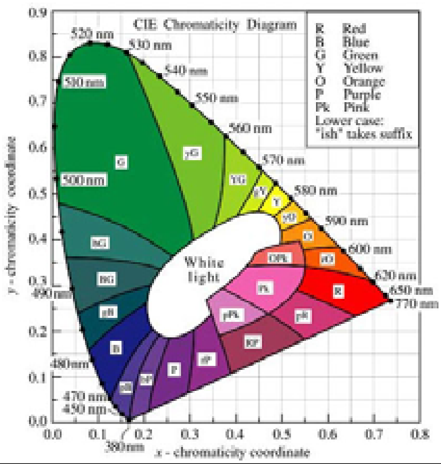
Colour measurements
The next step is to measure a colour. Again there are several methods, but the one most often used is the colour space as described in 1931 by the Commission inter-

Figure 9

Perceptual colour space



CIE xy-chromaticity diagram



Different methods to express colour parameters.

Figure 10

Unsaturated colours | Saturated, vivid colours

Left: NLG 5/Vondel 1 (The Netherlands, issued in 1966). Design: R.D.E. Oxenaar.
Right: NLG 5/Vondel 2 (The Netherlands, issued in 1973). Design: R.D.E. Oxenaar.

nationale de l'éclairage (CIE), the CIE 1931 xy-chromaticity diagram. An example is given in Figure 9. The achromatic centre of the xy-plane represents the locus of all grey shades, including black and white. Since this study focuses on applied design, we leave this colour metric subject here.
The colour wheel for the euro was well designed for people with normal vision, based on the 'artistic' colour scheme of Johannes Itten, but as said, the perception of this colour scheme by the colour-blind was not investigated. As a follow up it would be useful to construct a colour scheme based on the CIE xy-chromaticity diagram.

Vivid colours
Earlier guilder banknotes were monochrome, but not vivid. The first banknote with a vivid colour was the NLG 10/Frans Hals, issued in 1971 (Figure 3). This note was the first of a new series and when this series was finished, the 'old' NLG 5 was made more vivid to become a full member of this new series as is shown in Figure 10. This is a clear example of how a banknote design will improve for the colour-blind by changing the colour saturation. The large numeral was also further optimised.
Fortunately the requirement of vivid colours matches with preference of the general public, which has an aversion to pale banknote colours [81].

Strong colours can be easily reproduced by colour copier
Strong colours are much more readily reproduced by colour copiers than are soft pastel colours and thus undermine the security of banknotes. This is the reason why anti-copy features like silver-coloured foils and special inks (e.g. iridescence) appeared on banknotes around 1990 (see e.g. Figure 57).
Nevertheless, it is possible to reserve a section of the note for the brightest possible hue of a dominant colour, while keeping other sections paler, as is the case with the euro banknotes (Figure 11). From a security point of view this is an advantage,

Figure 11

Light side
Low density

Dark side
High density

The left part of the euro notes is light, while the right part is dark. For a counterfeiter this is difficult to copy with exactitude, and the counterfeit will either become too dark or stay too light.

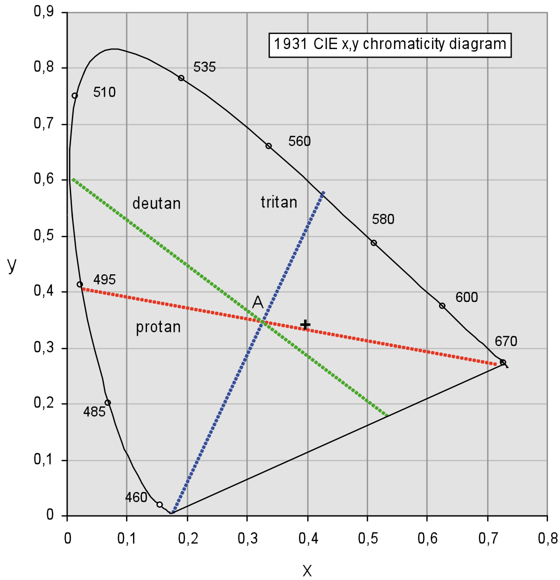
because the counterfeiter has to reproduce the complex variety of the dark and light hues as featured on the original note. If this is still true to date is a question mark, since personal computer equipment like scanners and printers is now so good that the era of 'hard to copy colours' seems to have come to an end.

Banknote paper hue
All denominations of the former Dutch guilder banknotes had the same off-white paper tint that is optimal for good printing contrast. However, today such off-white paper tint is available in many colour copiers and printers (recycled paper). And, furthermore, once a counterfeiter has imitated the right paper tint for one denomination, it can be used for the complete series. That is why a special coloured paper tint is more secure. Choosing the paper tint the same as the main colour of the note will support the colour perception of the note, which is the case with the euro banknotes. The blue 20 euro, for example, is printed on pale blue coloured paper and the green 100 euro on pale green paper. For the euro denominations a lighter version, a de-saturation of the dominant banknote colour would be better because of a higher print contrast for the large numerals (see also Chapter 4).
Such individual paper tints will also prevent counterfeiting through bleaching as well as re-printing of the higher-value notes.

3.5 Improvement of euro banknotes for the colour-blind

Recapturing the colour-blind would like:
- Suitable colour scheme,
- Monochrome and
- Vivid colours.

Figure 12

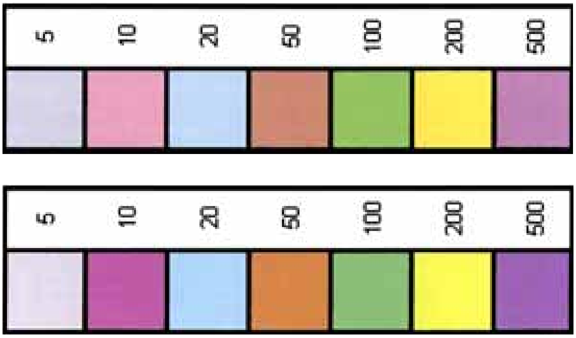


Same chromacity diagram showing protan, deutan and tritan dichromatic confusion lines [68].

Now we understand these needs we may also understand the criticism of the colour-blind on the euro banknotes. The colour-blind can barely distinguish between the colours of the 5, 10 and 20 euro (shades of blue and grey), while the 50, 100 and 200 euro are also perceived as similar colours (shades of green and yellow). The notes of 20 and 500 euro are also quite similar to them (Figure 5). This phenomenon can also be measured within the xy-chromaticity diagram, as is shown in Figure 12. The three lines drawn are so-called dichromatic confusion lines. A confusion line has the property that all colours located on the line are perceived (by dichromats) as having the same chromaticity. Banknotes on a confusion line are perceived as having the similar colours.
The confusion lines for protans, deutans and tritans, fan out from different locations.

Conclusion regarding euro colour scheme
Switching the colours of the green 100 and the purple 500 would make the euro colour wheel better for the colour-blind. However, this was not advised by Blind Color. Their conclusion is that the basic colour scheme of the euro banknotes also accommodates the colour-blind. Blind Color did advice to improve the colours of the individual notes (see Figure 13). Especially the magenta of the 10 euro banknote and the orange of the 50 euro note might be more vivid (brighter). The purple of the 500 euro could also be made more vivid [68].

Figure 13



colour scheme of
euro banknotes

suitable colour scheme for
colour-blind

Top: current design euro series as determined with the DoCol-method.
Bottom: optimised colour scheme for aiding the colour-blind (deuteranope).

Euro banknote colours are OK for normal vision

The criticism of the colour-blind is, of course, not shared by people with normal vision. The euro banknotes are found easy to be distinguished and handled was the opinion of 94.1 % of the Europeans in 2006 (in NL 93.2 %). These qualities are not attributed to the euro coins: after 5 years of use a large group still find the euro coins difficult to distinguish and handle (25.3 %, in NL 30.9 %) [75]. Earlier surveys conducted in the period 2003 - 2005 showed quite similar results (see Flash Euro barometer 2003, 2004 and 2005) [58, 63, 70]. These findings were confirmed by research by the Banco de España: euro banknotes are assessed more highly than euro coins. As for the banknotes, the Spanish appreciate the colours far more (61 %) than the dimensions (16 %) [98].
Appendix 2 explains the rather poor score of the euro coins.

3.6 Check against user requirements

Table 4 lists all the user requirements against the designed features for the colour-blind in case of the euro banknotes. These requirements are largely based on the requirements set by the NRC and EBU [37, 38].
The euro banknotes perform quite well for the colour-blind. They have at least two good features: the colour scheme and the monochrome colour setting. The vividness of the colours used could be increased. Some of the single colours could also be improved upon (as said especially those of the 10 and 50 euro, but also the 500). The colour-blind will also profit from features specifically designed for the partially sighted, like e.g. large numerals and the 'silhouette main image'. These features are described in Chapter 4.

Table 4

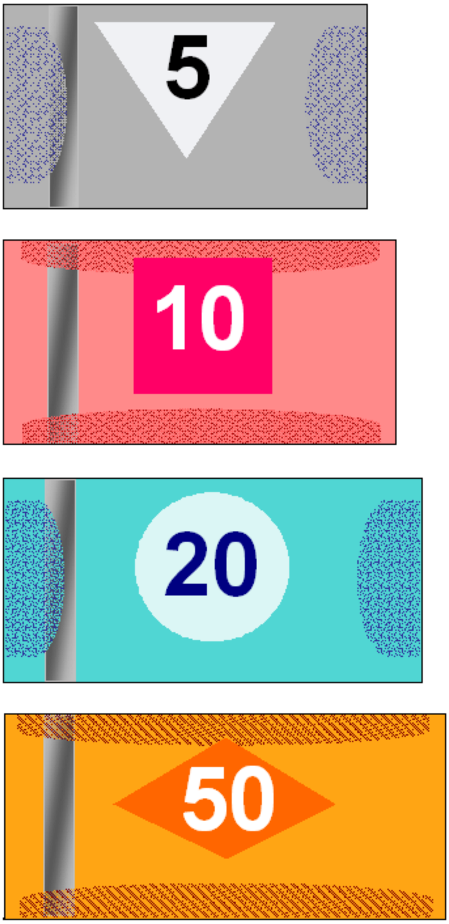
User requirements for the COLOUR-BLIND	Features to assist the colour-blind with denominating different euro banknotes Feature 1 Colour wheel	Feature 2 Mono-chrome	Feature 3 Vivid colour
1. Denominating time < 3 seconds	+	+	+
2. Confusion error < 1 %	+	+	o
3. On low denominations	+	+	+
4. On all denominations	+	+	+
5. No assistance needed	+ +	o	o
6. No additional tool needed	+ +	+ +	+ +
7. Discretely	+ +	+ +	+ +
8. Standard (position) front	+	o	o
9. Standard (position) reverse	+	o	–
10. No training needed	+	+	+
11. General quality of feature	+	+	o
Central bank			
12. Long-wearing, remains readable	+ +	+	+
13. Difficult to simulate	– –	– –	– –
14. Inexpensive use	+ +	+ +	+ +
15. Low cost for producer	+ +	+ +	+ +
16. Low social cost	+ +	+ +	+ +
17. Non destructive to banknote	+ +	+ +	+ +

Overview of the user requirements of the colour-blind and the features designed to assist the colour-blind in determining the value of a euro banknote. Requirements 12 - 17 are coming from the central bank. Scored by author.
+ + = yes or very good, + = yes or good, o = neutral, – = no or poor, – – = no or very poor.

3.7 Synthesis: new banknote concepts for the colour-blind

The design requirements are the input for the synthesis phase of new design concepts. Some directions are provided, demonstrating that the analysis done will give birth to innovative banknote designs. The colour-blind would be best served with a series design based on their optimal colours (see Figure 14). Such design should also be acceptable to others. The central bank may shy away from such an optimal colour design, considering it too far removed from the existing designs.

Figure 14



Banknote series optimised for the colour-blind, using an optimal colours: monochrome and evenly distributed.

3.8 Historical overview

This chapter ends with Table 5, a short historical overview of the first introduction of special banknote features for the colour-blind.

Table 5

COLOUR-BLIND

WHEN	BANKNOTE	WHAT IS NEW?	BY
± 1800	many examples	Monochrome banknotes	most central banks
1971	NLG 10/Frans Hals	Bright colour within monochrome banknote.	De Nederlandsche Bank
1992	KGS-series	Colour scheme for complete series (Kyrgyzstan Som)	IMF, DNB and Central Bank of Kyrgyzstan [34]
1995	Euro design	Colour scheme for complete series based on human perception.	De Nederlandsche Bank
....	....	....	....
1997	Second Series NIS	Colour-blindness study of new banknote design using colour-blindness simulator.	Bank of Israel
2002	Euro series	Colour scheme for series based on 1995 proposal with two colours switched.	European Central Bank
2002	Euro Series 2002	Criticism. Images of colour-blindness simulator.	Blind Color, NL [51]
2005	Euro, 2 Year Project	Colour-blindness study new banknote designs using dominant colour method (DoCol).	De Nederlandsche Bank/European Central Bank [68]
2008	Euro, study ES2 (50)	Colour-blindness study new banknote design using monochrome colour method.	De Nederlandsche Bank/European Central Bank [87]

Milestone overview of the development of dedicated banknote features for the colour-blind (as far as known).
Above the dotted line are features that are already suitable for use by the colour-blind, but were not intentionally designed for the colour-blind.

4 Partially sighted

This Chapter deals with the banknote denomination features for the partially sighted, a sub-category of the visually impaired. Using the history as a lead, the focus is (again) on what the central bank and the graphic designer of the banknote can do especially for the partially sighted. Since this history has never been recorded, a bias towards the Dutch banknote design is possible. The partially sighted will also profit from features first of all designed for the colour-blind and blind. The colour wheel is for example described in Chapter 3, while banknote dimensions are discussed in Chapter 5.

Based on today's knowledge, the following design requirements should be taken into account:

- Numeral frequency: one, two, three or four numerals?
- Position of the numeral on the note,
- Numeral size,
- Font (letter type),
- Colour of the numeral,
- Contrast of the numeral,
- Positive-negative numerals,
- Alternation of positive and negative numerals through the series,
- Colour scheme of the note series,
- Banknote colour,
- Banknote orientation,
- Silhouette design,
- Banknote dimensions.

These topics will be addressed in the sections 4.2 - 4.14, after a description of the partially sighted. This account also reports on some alternative design solutions (section 4.15):

- Distinctive marks to recognise a note's value.

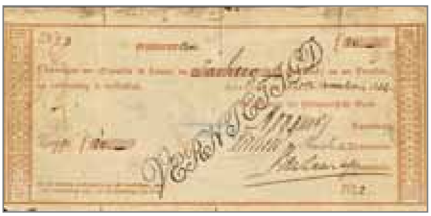
4.1 **Partially sighted**

Low vision, the term also used to denote ‘partially sighted’ or ‘poor-sighted’ is often defined as best-corrected letter acuity less than 6/18 m in the better eye (or 20/60 in foot). People with such vision are unable to read newspapers [37]. Many partially sighted suffer from tunnel vision; their vision field is not around 180° but jus a part of it.

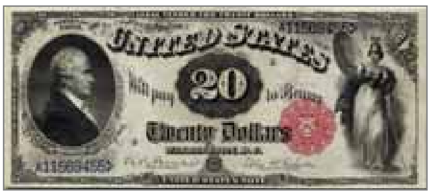
Over the years, people tend to lose quality of sight by developing lower contrast sensitivity and a decreasing pupil size. Around the age of 80, the eye often admits only one-quarter of the light admitted for a 20-year old [82]. As the geriatric population grows, the number of people with low vision will increase. Partially sighted prefer to use their rest vision to denominate banknotes instead of using touch.
Tactile sensitivity also diminishes with age; older people have less tactile sensations. Professor Dinse writes in 2008: ‘There is a tremendous age-related decline of performance over age, which starts already at an age of 30 to 35 and then almost linearly continuous to decline over the rest of the lifespan. The ability to tell two closely spaced points in space apart is worsening over age.’ [99].

Figure 15

Handwritten, small numerals (NLG 80, 1814)



One numeral in the centre (USD 20, 1880)



Numerals in all 4 corners (NLG 25, 1860)

No numerals (FFR 100, 1923/1937)

Examples of value indication on early banknotes.

Figure 16

NLG 50/Sunflower, 1982

NLG 10/Kingfisher 1997

Since 1980 the NLG-notes feature just one large numeral on the front.

4.2 **Numeral frequency (1, 2, 3 or 4 numerals?)**

Early banknotes were receipts in return for the gold and silver coins deposited at the central bank. These receipts did not look like the banknotes as we know them today. The numerals on these banknotes were not very obvious (Figure 15). The NLG 80 banknote issued in 1814 in the Netherlands is an example of this archetype. The numerals were filled in by hand on a standard position. The receipt type was followed by the archetype featuring a numeral in each corner, like the NLG-series issued around 1860 [31, 46]. This archetype is still used today, e.g. on USD banknotes, although earlier dollar designs had a large numeral in the centre.
Many banknotes today feature two numerals on the front, e.g. the yen and euro banknotes, for the value should be recognisable on folded banknotes too, it is argued. The Dutch banknotes had just one large numeral on the front (Figure 16). The EBU recommends two large numerals on the front [38].

4.3 **Position of the numeral on the banknote**

After the central bank has decided on the frequency of the numerals, the next question is: what is the best position for the numeral(s)?
Again, from a historic point of view the centre of the note was frequently chosen for the position of the numeral. In the early days the banknote's value was written in words, e.g. 'Hundred Francs' *(Cent Francs)*. In most cases small numerals were added in the corners. Quite uncommon at that time was to use only one numeral.
Later the numerals moved more towards the upper left corner – i.e. another natural location – since in the west reading starts from left, beginning at the top. Graphic designers are familiar with the term 'images left', because images are processed by the right part of the brain. This brain part receives most stimuli from our left eye.
According to the NRC the denomination numerals should be printed in the same position on either side of each banknote in a series.

Figure 17

Two examples of modern banknote design with the large numerals in other areas than one of the corners or the centre of the banknote. Such designs often lead to a suboptimal contrast between the numeral and the background.
Left: Spain: ESP 1,000, issued in 1992 (design: Reinhold Gerstetter).
Right: China: CNY 100, issued in 2005.

In an attempt to arrive at different designs, numerals are moved to other, suboptimal positions (Figure 17). This is allowed, since an optimal reading position seems to be of less importance than a standard position for numerals. In their search for alternative positions for numerals, central banks and graphic designers often forget about a clear contrast between the numeral and the background.

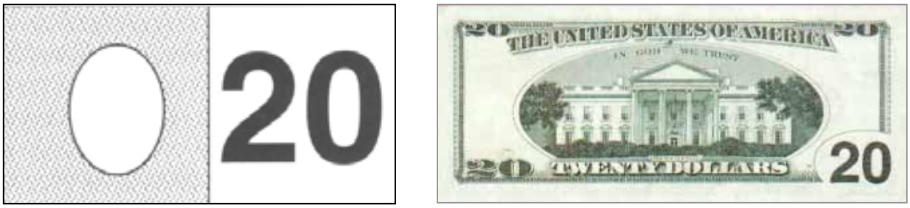
4.4 **Numeral size**

The next characteristic to be decided on – after frequency and position – is the one on the dimension of the numeral. Central banks traditionally focused on the very small texts in a banknote, the so-called micro-texts instead of the large numerals [22]. The Monopoly money with its large, clear numerals and bright colours certainly inspired the Dutch banknote designer Ootje Oxenaar, a very successful designer of Dutch guilder notes over the years 1965 - 1986 (Figure 18) . His first design was the NLG 5/Vondel 1 (Figure 10). The character height of the numeral, the large

Figure 18

Monopoly money 1935, optimised for quick value recognition during the game.

Figure 19



Left: A real tall numeral against an uncluttered background presented in the report of the NRC in 1995. Right: Reverse USD 20, 1996 series, using 4 numerals. One tall numeral in the left bottom corner: 14 mm high.

5, was designed at 18 mm. After this design, the numeral height on subsequent Dutch banknotes was required to be at least 15 mm and the numeral width at least 2.5 mm [e.g. 13]. These requirements were used as input by the EBU for their 1995 recommendations [38]. The numeral height of the euro series is between 21 mm (euro 10) and 26 mm (euro 5) and fully meets this EBU-requirement.
Since space on a banknote is limited, central banks might opt for one large numeral, which might take up even less space than four small numerals together!

USD banknotes

The denomination of USD banknotes is typically indicated by numerals with a height of around 10 mm. In 1996 the 'tall numeral' was introduced: a 14 mm high figure on the reverse of the note. This figure corresponds with the visual limit for someone with 6/13 m acuity (or 20/40 in foot) at a reading distance of

Figure 20

New USD 5 note, issued in 2008. Introduction of a large numeral on the reverse side; letter height about 26 mm. The new letter type is selected from the Universe/Helvetica types, a sans serif letter family. This is an improvement since the rounded serifs of the typical Gothic-letter type for the USD-notes are sub-optimal for the poor sighted. 'We wanted this redesigned bill to scream, 'I am a five. I am a five.' says Larry Felix, director of the Bureau of Engraving and Printing [84].

Figure 21

CAD 10 issued in 2001. Large numerals (22 mm) on both front and reverse. One in positive and one in negative. Area around the numerals 4 mm.

0.4 m (16 inches). With this 1996-series the Treasury followed only partly the recommendation of the report of the NRC: numerals should be larger than half the note's height of approximately 65 mm, which was illustrated with a sketch – Figure 19 – of a conceptual note with a maximised numeral, using nearly the full width of the note [37, 82]. A second response of the Treasury came in early 2008: the new USD 5 banknote features a large of 26 mm tall numeral 5 (Figure 20).

Canadian banknotes
Larger numerals were also first advised in 1982 by the Bank of Canada [10]. A second enlargement to around 22 mm (78 pt) – about 30 % – was realised in 2001 with the Canadian Journey Series as shown in Figure 21 [79]. The 2001 Canadian banknotes were the first to feature large numerals on either side.

4.5 **Font (letter type)**

The selected font type on the CAD 10 was 'euro style sans-serif' and was slightly modified to address concerns raised by invited vision specialists. The small elements added to the edges of a letter are called 'serif'. Letters that have plain or squared off edges are called 'sans-serif' fonts. Well known banknotes using a serif letter type are the US dollar notes, while the euro banknotes are, like the Canadian notes, using a 'sans serif' letter type (Figure 22).

In general the readability of 'sans serif' letter types is better. The numerals on guilder notes required also a font without serifs. It was also stipulated that the font should not be enhanced with shadowing, outlines, embossing or other effects [e.g 13].

Figure 22

Letter type serif | Letter type sans-serif

Example of a banknote with a serif letter type and without serif (sans serif).
Left: USD 1 banknote (first issued 1929).
Right: EUR 20 banknote (issued 1 January 2002). Design: Robert Kalina.

Both Dutch designers Oxenaar and Drupsteen preferred to start with existing fonts within the Univers/Helvetica families and modified these fonts for their design.

4.6 **Colour of the numeral**

The choice of a purple 5 on the green reverse side of the new USD 5 is remarkable, because of its clear contrast with the green (Figure 20). The idea behind this design is probably the signal effect, as is also the case on the latest Danish banknote

Figure 23

Signal colour | Complementary colour

Two examples of numeral colours deviating from the main banknote colour.
Left: signal colour orange used for the colours on the DKK 50 and 200, reverse side, 1997.
Right: complementary colours used in the designs by Roger Pfund, Euro banknote design contest 1996.

designs (Figure 23). The question arises if such colour combination like purple and green are also suitable for the colour-blind.

Signal colours
Signal colours are used on products that ask for attention, like sales advertisements, fire brigades or police cars. Such colours are usually pink, orange, yellow, red or green, and often fluorescent. A bright orange colour in a green banknote will be noticed more quickly than a green figure, so is the argument.

Complementary colours
Instead of signal colours, a central bank may also opt for complementary colours, as is done by Roger Pfund in the design proposal from Banque de France for the euro banknotes in 1996 (Figure 23).

Numerals should be in the banknote's colour
Although there are certainly arguments to print the numerals in a signal or complementary colour, the advice would be not to do so. Such deviating colours will compete with the banknote's main colour and might confuse the user. To give attention to the numerals it is better to give them enough space against a 'quiet' background.
In most cases central banks opt for numerals in the same colour as the banknote. Figure 24 provides two examples demonstrating the user's hesitation to tell the banknote's main colour!

Figure 23

What is the main colour of these banknotes?

Test yourself: what is the main colour of the note? You may pick just one colour!
Left: Convertible 20 pesos banknote, Cuba (issued in 1994). Three answers are possible: blue, red and brown!
Right: Belize, 50 dollar (issued in 2003). Again three answers possible: orange, purple and green.

4.7 Contrast of the numeral

The next step is to decide on the contrast of the numeral. The numerals on the euro banknotes are not easy to read, although they are large enough. The reasons are a low printing contrast and an inhomogeneous background.

Reading speed of numerals influenced by contrast
The reading speed – next to numeral height and a homogeneous background – depends on the contrast. Tinker and Paterson already found in 1931 that the reading speed of a text was faster for black letters on white paper than for any other colour combination. Green-on-white was 3.0 % slower, green-on-red 10.6 % slower, red-on-green 39.5 % slower and black-on-purple 51.5 % slower. They suggested that luminance contrast is the more important determinant of reading speed [2, 5]. Luminance contrast was first defined by Michelson in 1927 as the Print Contrast Ration (PCR) [1] and used by the National Research Council in their 1995-report. See also Appendix 3.

Table 6

Banknote	Date of issue	PCR (D average) in %
NLG 5/Vondel 1	1966	62.1
NLG 5/Vondel 2	1971	72.1
NLG 10/Frans Hals	1973	69.2
CAD 10/Canadian Journey	2001 Front	72.2
	Reverse	- 62.6
CAD 10/Canadian Journey	2005 Front	66.1
	Reverse	- 61.6
USD 20	1996 Reverse	53.0
USD 5 (purple numeral)	2008 Reverse	52.0
EUR 5	2002	17.6*
EUR 10	2002	42.7
EUR 20	2002	39.1
EUR 50	2002	22.9*
EUR 100	2002	32.2
EUR 200	2002	35.6
EUR 500	2002	32.6

*) without the dark areas of the main image

Overview of PCR values measured on different banknotes.
Measurement tool: Konica Minolta spectrophotometer CM-2600d. Settings: measurement area = diameter 3 mm, full spectrum from 360 - 740 nm Observer: 10°. Light source: D65. Conversion of spectral data to: ISO visual density according to ISO 5-3:1995. Operator: Mr. Tom Buitelaar (DNB), January 2009 [100].

PCR > 80%

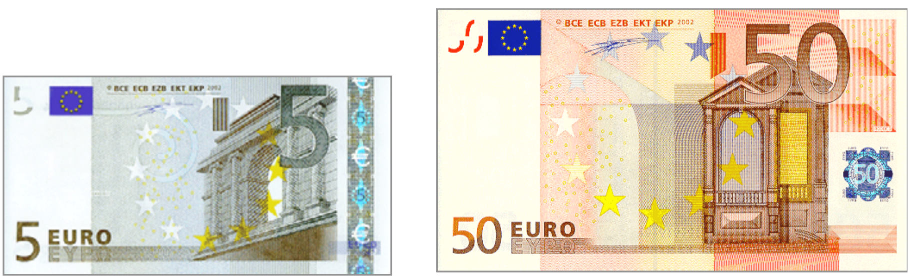
In the case of the NLG notes, DNB required a PCR of at least 80 % [13]. The Bank of Canada targeted the same for their Canadian Journey Series issued in 2001. The NRC advised a contrast of at least 85 %. In the case of the NLG notes, the PCR was never really measured. In 2007, the Bank of Canada reported that they did not reach their target; the PCR ranged from 74 % to 78 % [79].

In 2009, DNB developed a measurement method and for the first time measured banknotes' PCR values, including those of two CAD 10 banknotes. The results are presented in Table 6, measured according to the method described in Appendix 3. The average density has been determined by making 5 measurements per individual numeral and 5 measurements for the corresponding background. For the euro 200 note, a total of 15 measurements were performed for the numerals and 15 more for the corresponding background, resulting in an average density value for both the numerals and their backgrounds. Although the density for the other banknotes listed in Table 6 is in general more uniform, the same approach was used for these notes as well.

Low PCR for numerals on the euro banknotes

None of the banknotes meet the PCR (D) > 80 % criterion. The highest score of 72.2 % is found for the CAD 10 issued in 2001, not far from the figures reported by the Bank of Canada. The method described has also been applied to the euro banknotes. In euro banknotes, the density and colour of the large numerals and surrounding background is not uniform (Figure 25). The result is a poor PCR performance. The best euro banknote is the euro 10 note; the least readable are the euro 5 and 50 notes. The legibility of the euro 5 and 50 is impaired by the partial melting of the numerals with pictorial elements. In 1995, the NRC advised to print large numerals on a surrounding clear field. The contours of this field behind the numeral(s) should follow the characters at a distance equalling the numeral's width.

Figure 25



Suboptimal readability of large numerals on 5 and 50 euro banknotes caused by a lack of contrast and a cluttered background. If the banknotes in a series differ in length and height, design problems will arise because of scaling. The large numerals on the large banknotes appear smaller than the large numeral on the small sizes.

Table 7

	Partially sighted	Blind
Seeing numerals	78 %	23 %
Seeing colours	53 %	20 %
Comparing lengths	47 %	81 %
Comparing widths	22 %	54 %
Feeling lengths	20 %	48 %
Feeling widths	14 %	32 %

Overview of the evaluation of the euro banknotes by the partially sighted (visual acuity between 6/18 and 6/60 m) and blind (visual acuity above 6/60 m). The percentage denotes the number of respondents who answered positively. EBU-study 1999 [45].

In case of a numeral height of 22 mm, the thickness of the digit will be about 3 to 4 mm. Such numeral design will also assist normally sighted users in denominating banknotes under low-light conditions or during hectic transactions.

A light paper tint is necessary for a good contrast (or a very bright absorbing printed ink). The light green-yellow tint of USD banknote paper limits the print contrast ratio that can be achieved between printed denomination numerals and their background. Also the paper tints of the euro could be further optimised for optimal legibility contrast (see also Chapter 3).

Criticism on euro banknotes
The findings reported in Table 6 are in line with earlier complaints of the Dutch partially sighted about the legibility of the large numerals on the notes, especially on the 5 euro note. The numerals should be free from any other design element. These remarks were heard before from the European Blind Union. In 1999 they reported that less than 80 % of the partially sighted were able to read the numerals of the euro banknotes (Table 7).

Finally, a simulation of the euro banknote series by Blind Color in 2005, obtained by blurring of the images, also indicated the limited legibility of the numerals on the euro banknotes. Test yourself using Figure 26!

4.8 Positive and negative numerals

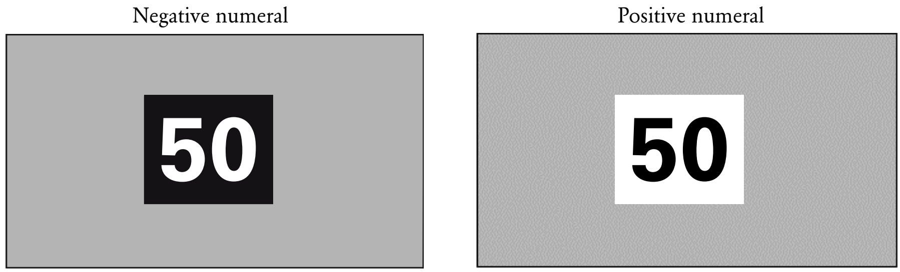
A new design parameter for banknotes was introduced in 2001 by the Bank of Canada. Research done by vision specialists concluded that the large numerals should be printed in both a positive – a numeral using a dark colour on a light

background – and a negative numeral [79]. This is appropriate because many visually impaired individuals find it easier to recognize pale numbers against a dark background, although the Canadian research concluded that most people preferred dark on light. This principle is shown in Figure 27 and is brought into practise on the Canadian Journey Series (Figure 21).
Under very low levels of illumination white characters on black are the more legible, whereas under high illumination black on white is more legible [3]. Since banknotes are frequently seen under poor lightning conditions, for example in your wallet, a negative numeral is preferred for the front.

Figure 26

Euro series 2002 as could be experienced by poor sighted, simulation by Blind Color. This is just one example of how people with low vision may experience the euro banknotes; others are tunnel vision and areas falling away.

Figure 27



Test yourself: which one reads best?
In line with the research done by the Bank of Canada, about half the people favour the design on the right and the other half the design on the left. On 17 February 2009 your author performed this test on 40 of the participants during the presentation 'Banknote design for the visually impaired', with similar results.

Positive and negative numerals on frond and reverse

In 2003, the Central bank of Serbia issued a new series of CDS banknotes. These notes have both a positive and a negative numeral on their front and also on their reverse sides (Figure 28).

Figure 28

The latest Serbian banknote CDS series; first note issued in 2003 includes two large numerals on each side: one negative and one positive numeral.

Figure 29

With the introduction of the 1996-series with a large off-centred portrait, the Federal Reserve System introduced alternation of dark and light numerals within the series. This system was abandoned with the next series starting in 2006.

4.9 **Alternation of positive and negative numerals within a series**

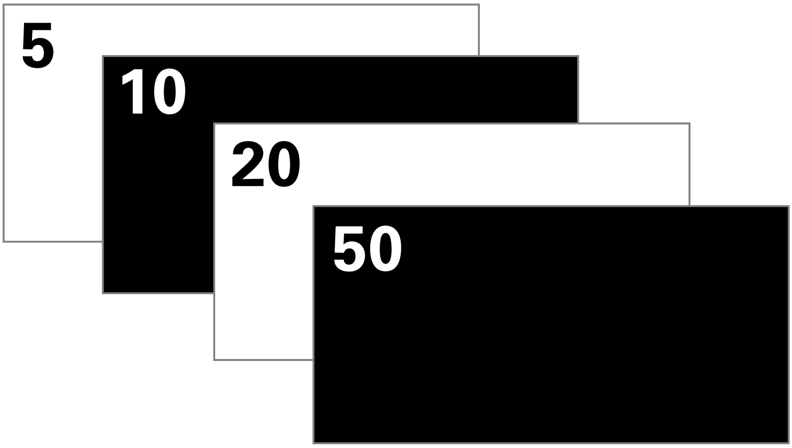
An uncommon design variable is to alternate positive and negative numerals within a new series of banknotes. Such alternation between dark and light numerals would help in distinguishing consecutive banknote denominations, like the 10 and 20 euro. An example of such a design principle is the 1996 series of the US dollar (Figure 29). The design of this alternation principle was not very convincing, probably because the dark numerals did not receive a light background. The USD 2006-series abandoned this alternation. However, if the designer sticks to the principle it might serve to distinguish banknote denominations within a series. Figure 30 is an example of an optimal situation, using only black and white.

4.10 **Colour scheme of banknote series**

The colour scheme for the complete banknote series is discussed in Chapter 3 on the colour-blind, since this scheme should first of all be beneficial to them. Also for the partially sighted, however, the colour scheme should be further optimised at some points.

Adaptation of colour schemes necessary
Often the colours of banknotes are based on the history of the denomination. The Dutch 10 guilder note has always been blue ever since it was first introduced in 1904.

Figure 30



Conceptual design of a banknote series with, alternately, numerals in positive and negative print throughout the banknote series. Concept by author.

Once used to the main colour, people do not like to see it changed. With banknote colours becoming brighter, historical colour schemes were adapted, as was the case in Switzerland. 'With its previous light blue colour, the 20-franc note was frequently confused with the 100-franc note, and its colour was thus changed to red/dark-red.' [66]. Also other central banks experienced difficulties with their colour scheme. When in Germany the blue DEM 100 was introduced in 1994 people sometimes confused it with the purple DEM 10 (Figure 31a). The Russian central bank received comments on the similarity of the blue and green colours used in both the RUB 10 and RUB 50 notes (Figure 31b). Although the readability of the numerals was optimised by vision experts and the colours of the notes are bright, the CAD 5 and CAD 10 notes are still suboptimal because of their main colours (Figure 31c).

4.11 **Banknote colour**

Loosing their visual acuity over the years, many people with low vision will also loose their ability to see colours. With reduced clearness of vision it is more difficult to experience colours. Vivid colours will be seen better than grey scale colours. Also research done by DNB since 1983 concludes each time that colour is one of the most important design parameters. Spontaneous public name giving to banknotes, often using its colour, supports this conclusion further.

People name a banknote after its main colour

If colour is absent on the front of the banknote, people may use the colour of the reverse as basis for a nickname like ‘red back’ and ‘green back’. The said names are those given by the Dutch to the 1,000 guilder note issued in 1860 and by the Americans to the US dollar first issued in 1929, respectively. The Dutch 1,000 guilder note had a black front, and a red reverse. This note’s nickname ‘red back’ (in Dutch slang: rooie rug), similar to the ‘green back’ used for (all) dollar denominations since 1929. The term ‘red back’ is today still used as a synonym for an amount of 1,000 euro. An yellow Dutch banknote was introduced in 1862 and was called ‘little yellow one’ (in Dutch slang: geeltje, see Figure 15). The texts on this note were printed in black on a yellow background and the reverse was left unprinted. Despite the fact that this denomination had been red since 1921, this nickname was synonymous with 25 guilders until the introduction of the euro in 2002, when banknote units of NLG 25 and 250 were replaced EUR 20 and 200, respectively. In the days of the pre-Revolution also the Russians gave nicknames to their banknotes based on its colour, like e.g. canary to the yellowish one rouble.

Figure 31

(a)

(b)

(c)

Three examples of suboptimal colour wheel design.
a) DEM 10 and DEM 100 (series 1991). Colours of banknote denominations starting both with 10 should not have colours that are adjacent to each other on the colour wheel.
b) RUB 10 and RUB 50 (series 1997). Consecutive denominations should not have similar colours.
c) CAD 5 and CAD 10 (series 2001). Consecutive denominations should not have colours that are adjacent to each other on the colour wheel.

Figure 32

Minimal colour variation | Unsaturated colour variation | Vivid colour variation

Three examples of banknote series sharing the same main image and using colour as main design parameter. Going from left to right the colours range from a minimal to vivid use of colours (Surinam dollar issued in 2004, British pound issued by Royal Bank of Scotland in 2007 and Ghanaian cedis issued in 2007).

Taking this custom of the public into account, the central bank and the designer might use the banknote's colour as point of departure in their search for subjects. Looking for a 'yellow subject', the Dutch designers Oxenaar and Kruit proposed a sunflower for the NLG 50 issued in 1982 (Figure 16).

Colour design

Colour may seem an easy design parameter, but in fact it is not. To create a monochrome impression, while using other colours besides, is one of the challenges faced by the graphic designer. In several banknote series, colour is the main design parameter; some examples are supplied in Figure 32.

4.12 Alternation of orientation

Banknotes can be designed in two orientations: horizontal or vertical (or landscape versus portrait mode). Horizontal positioning is by far the most popular, although the very first banknotes, like the Chinese (1375) had a vertical orientation (1,000 Wen, issued 1375). Also in Japan (1746), Russia (1909) and several other countries portrait style banknotes were issued. After 1930 all banknotes were designed in the landscape style until the Swiss re-introduced this format in 1994. Several central banks followed, like Israel (1999), Colombia (2007), Venezuela (2007) and most

Figure 33

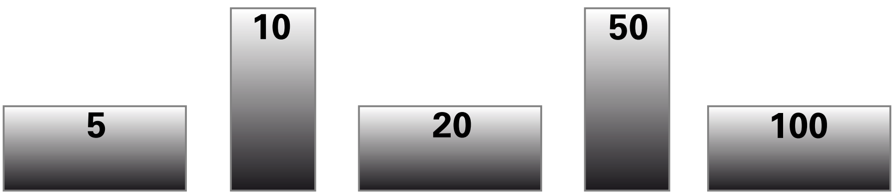
Switzerland 1995 Kazachstan 2006 Venezuela 2007 Colombia 2007 Bermuda 2009

Some modern designed banknotes using the 'portrait' format.

recently Bermuda (2009). Several central banks issued hybrid series, like the front in landscape and the reverse in portrait orientation or vice versa (The Netherlands (1982, 1986), Sri Lanka (1991), Spain (1992), Cape Verde (1992), Kazakhstan (2006) and Serbia (2006). Figure 33 provides some examples.

Alternating horizontal and vertical position
The orientation of a banknote is a very strong design parameter. Such a parameter may help to distinguish individual banknotes within a series. Alternating the horizontal and vertical position like done in Figure 34, would assist the determination of the denomination by the visually impaired. They would for example know: 20 is horizontal and 50 is vertical.

Figure 34



In this example the orientation of the individual banknotes is alternating from horizontal to vertical throughout the series. Concept by author.

4.13 Silhouette designs

The main image – if any – is the fourth value denominator for the partially sighted, after the numerals, orientation and the colour. The more characteristic the image used, the sooner the note's denomination will be recognised. Any image can be transformed into a specific spatial frequency. Silhouettes are in fact representations of the product in low spatial frequencies, representing global information about the shape, such as general orientation and proportions. High spatial frequencies, on the other hand, correspond to fine detail or silhouette edges.
A first example of such an 'inside silhouette design' is the NLG 100/Snipe (1981), followed by the Sunflower and Lighthouse (Figure 35).

This bird, i.e. the snipe, became so popular that the word snipe became synonymous with 100 guilder. Advertisements need just depict a snipe in order for people to associate it with the 100 guilder note. The public effect was almost similar to a silhouette of a Coca Cola bottle, which is also immediately recognised by people. An interesting question – beyond the scope of this section – is which design parameter prevails over the other. The bird image of the NLG 100/Snipe seems to prevail over the brown colour, for changing the colour of the snipe would not have confused the Dutch people. They still would have recognised the 100 guilder bird, in other words.

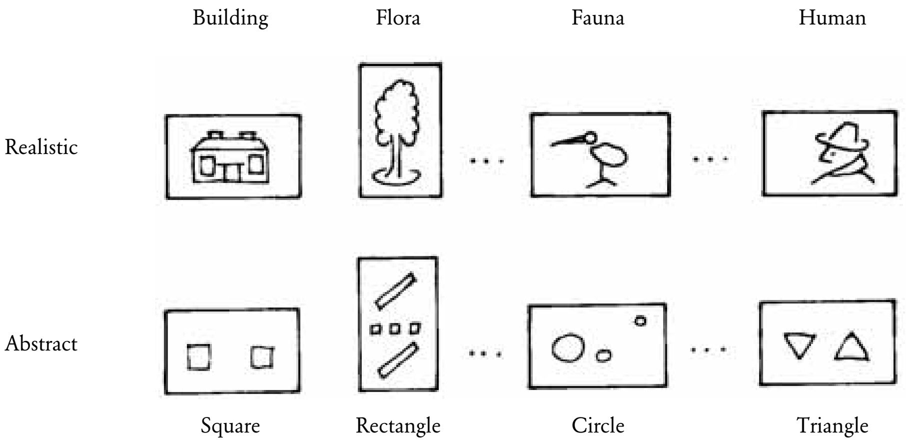
Brain paths
The more different brain paths are stimulated, the easier a banknote will be recognised. Banknote designs using subjects coming from different categories showing

Figure 35

Sunflower | Snipe | Lighthouse

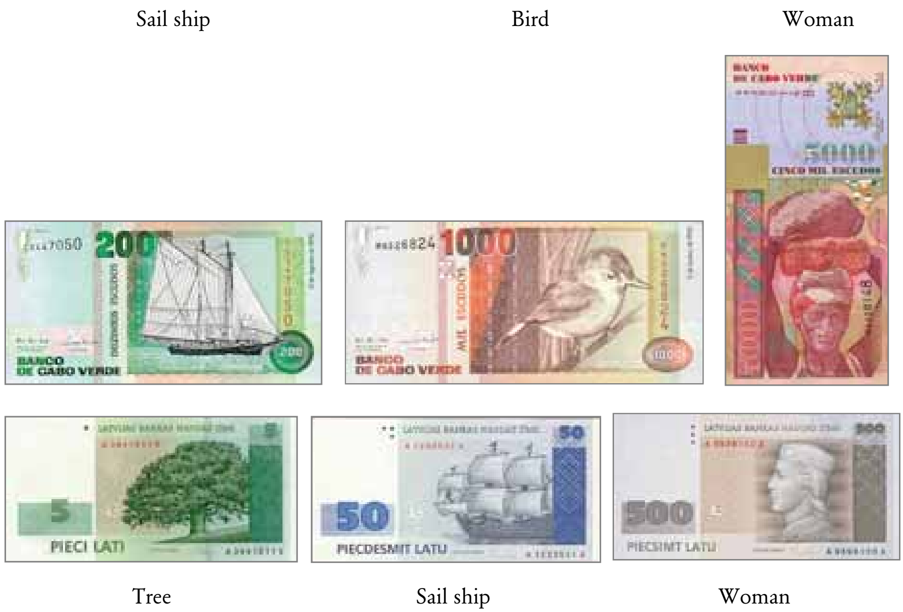
'House-tree-animal series' issued by DNB between 1981 and 1986: NLG 100/Snipe (1981), NLG 50/Sunflower (1982) and NLG 250/Lighthouse (1986). Designs: R.D.E. Oxenaar (100) and R.D.E. Oxenaar and J.J. Kruit (50 and 250).

Figure 36



Different ‘inside silhouettes’ are used in these conceptual banknote designs.
Above: realistic images. Below: abstract or mathematical images. Concept by author (1995).

Figure 37



Banknote design examples using an ‘internal silhouette design’.
Above: Three CVE-banknotes (Cabo Verde Escudo) issued over the years 1992 - 2000.
Below: Three LVL-banknotes (Latvian Lat) issued over the years 1992 - 2006.

clearly different silhouettes and printed in bright different colours stand the best change of being instantly recalled. By proving such an important contributor to banknote value recognition, the main image has a real user's function. A concept for such an ideal series based on different silhouettes is provided in Figure 36. Two more examples of such banknote series are given in Figure 37: Cabo Verde and Latvia.

Layout based on value

Jaap Drupsteen believed the designs of Robert Oxenaar could not be improved upon. Searching for a new approach to the Dutch banknote design contest in 1987, Drupsteen took the note's value as basis for his preset lay-outs (Figure 54) [81]. The resulting design ensured that even illiterate users could still determine the value. The underlying grid should always be clear off the edges, so that the value can be easily seen in your wallet.

Perceptional blindness of portraits on Dutch banknotes

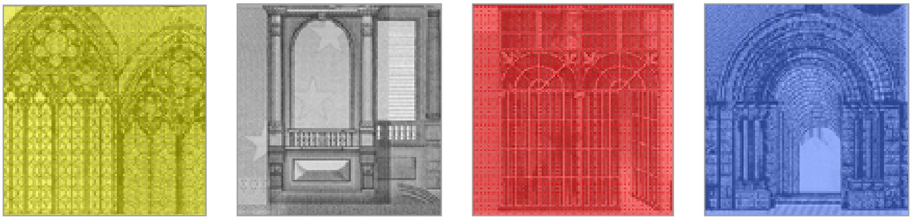
Colour may dominate a banknote design so much, that people might experience forms of perceptional blindness. In the early 1990s postcards appeared of Dutch banknotes (Figure 38). To by-pass the banknote reproduction rules, the smart producer took the portrait of the one note and printed it in the colour of another! The numerals were left out and the public did not notice the difference. These postcards

Figure 38

Original banknote   Postcard reproduction

An example of perceptional blindness of NLG banknotes. Switching the main colours is not noticed and is evidence for the perceptual dominance of colour over portraits.
Left: Original NLG 10/Frans Hals banknote issued in 1968 and NLG 25/Sweelinck issued in 1970.
Right: Postcards issued by Het Kaartenhuis in Amsterdam (early 1990).

Figure 39



Perceptional blindness of euro banknotes. Which euro banknotes are used?

were a first indication that the colour of these NLG-notes is dominant over the image. Such perceptional blindness reminds of inattentional blindness and change blindness. The first term was coined in the year 1998 by Arien Mack and Irvin Rock and refers to the inability of a person to see something that is present within one's direct perception. The second term, change blindness, is the phenomenon that occurs when a person viewing a visual scene apparently fails to detect large changes in the scene.
A more recent example of such perceptional blindness manifesting itself, is with the main image of the euro banknotes. Can you tell from which euro banknotes the images are taken in Figure 39?

Stroop effect
This phenomenon reminds of the well-known Stroop-effect, named after the research done by John Ridley Stroop and published in 1935 [4]. Stroop developed his colour word-task from an interest in interference between conflicting processes: reading the colours of the banknotes goes faster than reading the image. However, this is only true for a person who would not know '10 is blue'.
Figure 40 is a well known standard example of the Stroop-effect.

Figure 40

BLUE	GREEN	YELLOW
PINK	RED	ORANGE
GREY	BLACK	PURPLE
TAN	WHITE	BROWN

Example of the so-called Stroop-effect: naming the colours takes more time – on average 75 % longer – than reading the words. This is explained because we are able to read words more quickly and automatically than we can name colours. The delay and disruption occur when naming the colours, but not when reading the words.

The roots of Stroop's research evidently go back 50 years earlier, to James McKeen Cattell. In 1886, Cattel reported that objects and colours took longer to name aloud than it took to read the corresponding words aloud. In other words, saying 'squirrel' to a picture of a squirrel or saying 'red' to a patch of colour took longer than reading out the word squirrel or the word red. Surprisingly, no one thought to combine colours (objects) and words until Stroop. Since 1935, hundreds of experiments have been conducted on the Stroop effect.
The phenomenon is explained by two different theories. According to the 'speed of processing theory', reading the texts goes faster than naming the colours. The second theory of 'selective attention' explains that reading the texts requires less attention than naming the colours. The phenomenon provides a remarkable example of knowledge acting as a handicap: a person who could not read the words, through illiteracy or lack of knowledge of the language, for example, would not be slowed down!

Images in euro banknotes may be exchanged without this being noticed
The images of the euro banknotes are not delivering a characteristic silhouette for each denomination. It seems that images of euro banknotes may be exchanged without noticing, as long as the colours are maintained. Four examples are given in Figure 41. This phenomenon was researched by TNS NIPO in 2009 in order of DNB. It is alarming to see that when changing another image on one euro banknote many citizens are not able to distinguish the imitated banknote. When

Figure 41

Perceptional blindness in these euro banknotes; what has been changed?
Images prepared by Joh. Enschedé in order of DNB (2008).

Table 8

Banknote	Stimulus	Response	
		Correct (%)*	Wrong (%)**
Euro 5	Fake	16	84
	Real	85	15
Euro 10	Fake	28	72
	Real	79	21
Euro 20	Fake	44	56
	Real	77	23
Euro 50	Fake	42	58
	Real	53	47

Overview of the public recognition of fake and real euro banknotes.
* including correct but for wrong reason
** including doesn't know.

the arch on the 5 euro banknote is replaced by the window of the euro 50 this will not be noticed by 84 % of the respondents. Replacing the gate of the euro 10 by the gate of the euro 100, this will only be noticed by 28 % (including 13 % for the wrong reason). The aggregated results are provided in Table 8 [102, 105].

Figure 42

Geometric shapes used as device to assist partially sighted in denominating GBP-notes issued between 1990 and 1994 (E-series).

4.14 **Banknote sizes**

Banknote sizes will also help the partially sighted to denominate a banknote. However, today these banknotes are small, much smaller as 50 years ago (see Appendix 4). Looking once more at Table 7 it is clear that the euro banknote dimensions are only contributing after the numerals and the colour of the euro banknotes. The length increment helps the partially sighted and the blind much more than the height increment.

4.15 **Distinctive shapes**

In 1990, the Bank of England introduced a densely coloured shape on the front of each banknote in their new E-series to assist the partially sighted. The geometry as well as the colour of this shape differs for each denomination: a turquoise circle, an orange diamond, a purple square and a red triangle (Figure 42).
Why were these additional shapes introduced? In fact, they replace the poorly legible numerals and the multi-coloured design of the previous series. And the silhouette of the main image is always the same image of Queen Elisabeth II and is therefore not helping value recognition.
While those banknotes could not be read by the visually impaired and many others (see ref. 81 for an explanation), they proved useful in that they promoted instant value recognition (e.g. Figure 14).

The Central Bank of India introduced similar identification marks in 1996. In 2005, the designs of the South African banknotes followed this innovative principle in their upgrade of the 'Big Five' series. The distinctive shapes were larger and the contrast was increased compared to the British E-series. It can be questioned if this was really needed, since the ZAR notes are monochrome and have quite clear numerals

Figure 43

Introduction of geometric shapes on refreshed Big Five series in South Africa, issued in 2005.

(although small). The ZAR 10 note features a diamond, the 20 a square, the 50 a circle, the 100 a 'flat' hexagon and the 200 a 'honeycomb' hexagon (Figure 43).
The NRC reported such distinctive shapes in their 1995 report. The introduction of the off-centred and enlarged portrait on the US dollar notes in 1996 is seen as an accessibility feature [82]. However, this feature does not assist in distinguishing the notes within the new series and is only effective as means to discriminate the upgrade from the previous design.

Table 9

User requirements PARTIALLY SIGHTED	Features to assist partially sighted in distinguishing euro banknotes		
	Feature 1 Large numeral		Feature 2 Silhouette
	Letter type and height (~ 22 mm)	Uncluttered background	Main image
1. Denominating time < 3 seconds	+	–	– –
2. Reliable denominating	+ +	+	–
3. On low denominations (pay-back notes)	+	–	–
4. On all denominations	+	– –	–
5. No assistance needed	+	0	–
6. No additional tool needed	+ +	+ +	+ +
7. Discretely	+	–	–
8. Standard (position) front	+ +	+	+
9. Standard (position) reverse	–	+	–
10. No training needed	+	+	–
11. General quality of feature	+	+	–
Central bank			
12. Long-wearing	+ +	+	+ +
13. Difficult to simulate	– –	– –	– –
14. Inexpensive use	+ +	+ +	+ +
15. Low cost for producer	+ +	+ +	+ +
16. Low social cost	+ +	+ +	+ +
17. Non-destructive to banknote	+ +	+ +	+ +

Overview of the user requirements of the partially sighted and the features assisting the partially sighted in denominating different euro banknotes. Requirements 12 - 17 are coming from the central bank. Scored by author.
+ + = yes, very good, + = yes, good, o = neutral, – = poor, – – = very poor.

4.16 **Check against user requirements**

Similar to the colour-blind we check in Table 9 the designed euro banknote features for the partially sighted with its user requirements.

Two dedicated features for the partially sighted are advised:
1) large numerals,
2) silhouette design.

The partially sighted will also profit from features first of all dedicated to the colour-blind, like an appropriate colour scheme and a monochrome impression of the banknote including a vivid colour impression.

The scores for the euro banknotes in Table 9 are not good. This is mainly due to the rather low printing contrast of the numerals in all euro denominations. And, the background of the numerals in some denominations is rather poor designed (euro 5 and 50). Furthermore the numerals on the reverse of the euro notes are not large enough.
Also the second feature for the partially sighted is far from optimal. The main images on the euro banknotes do not contribute to the instant recognition of the different denominations. With lower spatial frequencies the main images – i.e. the window, door or gate – on the euro notes are not recognisable.

Euro colour scheme is OK for partially sighted
The euro colour scheme is working well for the partially sighted. After the large numerals the colour is the second design property for them (see Table 7). Just as people with normal vision, the partially sighted will recognise the value of a euro banknote by its dominant colour: red = EUR 10, blue = EUR 20 etc.

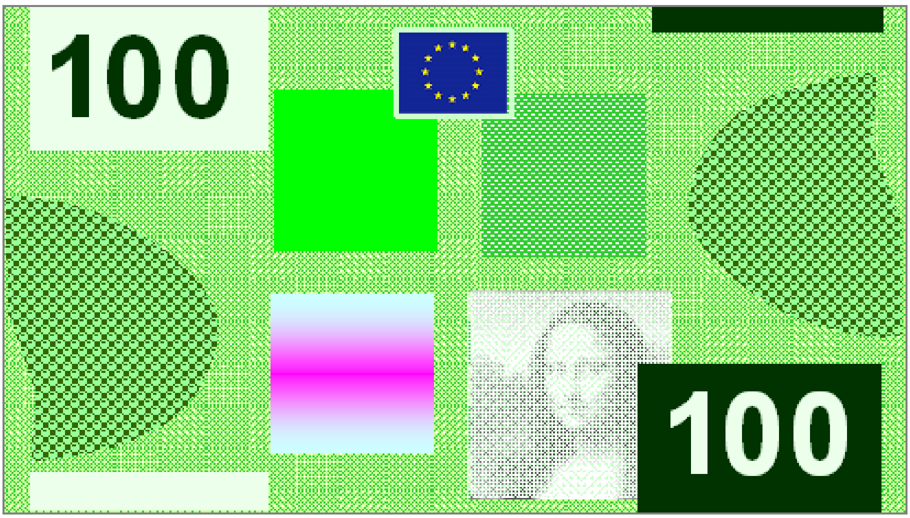
4.17 **Synthesis: new banknote concepts for the partially sighted**

Will the analysis done lead to new design concepts for banknotes? The answer is positive, some directions were already provided. This chapter is concluded with a conceptual banknote optimised for the visually impaired (Figure 43). Two large denomination numerals on the front against a homogenous background: one in negative and one in positive. It is a monochrome banknote design, using vivid green colours. The ‘silhouette’ is created by the four security features in the centre.

4.18 **Historical overview**

This chapter ends again with a summary history of the first introduction of special banknote features for the partially sighted is provided (Table 10). Before 1900, banknotes were not much used by the public. Since around 1970, innovations for the partially sighted happened in a more rapid succession.

Figure 44



Conceptual banknote for the partially sighted: clear large numerals, alternating between positive and negative against different geometric patterns. Secure tactile patterns are included at the short edges providing a codification for the blind. Maximum attention for the 4 security features in the centre (but not on the folding line). One security feature has a secure purple colour. Background could be used for other security features. Design by author.

Table 10

PARTIALLY SIGHTED

WHEN	BANKNOTE	WHAT IS NEW?	BY
1777	Scottish Guinea	Denomination in text ('One Guinea') in separate colour (blue)	Royal Bank of Scotland
± 1850*	various	Standard position numerals.	many central banks
1935	Monopoly money	Single colour, large numerals.	Charles B. Darrow, Parker Brothers, USA
1966	NLG 5 Vondel 1	Clear numerals on front, large (18 mm), clear contrast, plain sans serif letter type.	De Nederlandsche Bank
1971	NLG 10 Frans Hals	Banknote with clear predominant colour. Print contrast ratio large numerals > 70 %	De Nederlandsche Bank
1981	NLG 100 Snipe	Different silhouettes main image (animal-plant-building).	De Nederlandsche Bank
1989	NLG 25 Robin	Large numerals in tactile outline (30 mm), can be felt and followed with finger tip. Grid based on value. Value indication on all four borders of the banknote.	De Nederlandsche Bank
1990	GBP 5 G. Stephenson	Distinctive shapes printed in bright colour: circle, diamond, square and triangle.	Bank of England
1995	Euro design	Colour scheme for complete series based on human factors engineering.	De Nederlandsche Bank

PARTIALLY SIGHTED

WHEN	BANKNOTE	WHAT IS NEW?	BY
1996	DKK series	All numerals in signal colour, i.e. orange (on reverse).	Central Bank of Denmark
1996	Euro design contest	Numerals in complementary colour of the dominant colour of the note.	Roger Pfund for Banque de France
1996	USD 20 Series 1996	Tall numeral on reverse side (14 mm). Alternation of dark and light numerals of the denominations within the series.	Federal Reserve System
2001	CAD 10	Large numeral on front + reverse (22 mm). Numerals in dark (front) and light (reverse).	Bank of Canada
2002	Euro series	Colour scheme for series based on 1995 proposal with orange and yellow switched.	European Central Bank
2003	CDS series	Positive and negative numeral on one side.	Central Bank of Serbia
2008	USD 5 Series 2006	Tall numeral on reverse side (26 mm).	Federal Reserve System

*) Numerals on banknotes appeared around 1850, when the receipt archetype developed into the first banknotes as we know them today.

Milestone overview of the development of dedicated banknote features for the partially sighted (as far as known). Above the dotted line are features that are already suitable for use by the partially sighted, but were not intentionally designed for the people with low vision.

5 Blind

The history of banknotes issued with dedicated denomination features for the blind covers the longest period and is the richest. Although the smallest group of visually impaired, the blind received most attention of the central banks, it appears also to be the most difficult group to deliver satisfying denomination features. In the past two features were used: banknote sizes, varying both length and height, and tactile marks. Both features are loosing support. The banknote sizes have become too small for a reliable recognition of the banknote's value. And for the tactile marks the blind will tell the central bank 'Please do not come with another set of dots.' In 1996, the Austrian blind declared not to be in favour of such marks on notes in the new banknote series, attributing a stigmatizing effect to them. They preferred a good general tactility instead.
Fortunately, also compliments have been given, such as in the case of the Bank of Canada, which received praise for its designs from their national organisations for the visually impaired [79].

Based on its history, today the following design requirements should be taken into account:
- Minimise the number of denominations,
- Large length increment on pay-back money (with a standard note height),
- Tactile structure on all denominations (using the new intaglio gravure techniques),
- Smooth-rough for banknote orientation.

The first topic has been discussed in Chapter 2. The other three topics are addressed in the sections 5.3 - 5.5.

Some other design solutions have been tried but were not – or net yet – successful:
- Blind marks,
- Devices,
- Plastic, metal or carton tactile marks into the paper.

Some others are – until today – not feasible:
- Braille,
- Edge modification,
- Holes.

These six topics are addressed in the Appendices 5 - 9.

5.1 Blindness

According to the WHO a person is totally blind when they have no vision, no light perception at all. A blind person is functionally blind when, with the best possible correction, their visual acuity is less than 6/60 m and/or their visual field is no more than 20°.

Many nations have an accepted category of people referred to as 'legally blind'. Often this is the same as the definition of the WHO for the functionally blind. A difference is frequently made between the so called 'late blind' and the 'early blind'. Usually the border is set at 4 years. People that have become blind before they were 4 years old have – in general – a much better tactility in their fingers than the late blind.

What causes blindness?
People are born blind, others become blind by disease or accidents. The leading causes of low vision and blindness in the developed countries are diseases that are common in old age like cataract (47.8 % of total blindness), glaucoma (12.3 %), age-related macular degeneration (8.7 %), corneal opacities (5.1 %), diabetic retinopathy (4.8 %), childhood blindness (3.9 %) and trachoma (3.6 %). Figures refer to the year 2002 [62].
Diabetes is a cause for problems with eyesight. Age-related causes of visual impairment and blindness are increasing, as is blindness due to uncontrolled diabetes. Many diabetic patients became blind on a later age. On top of that diabetic people hardly have any tactile sensation left in their fingers. A relative high percentage of glaucoma patients are caused by high blood pressure. Glaucoma or retinitis pigmentosa can result in tunnel vision.

5.2 Analysis of the use of banknote sizes by the blind and by others

Do I receive the correct amount of change? Can I trust the shopkeeper? Should I ask somebody to check my change? Such questions arise when a blind person is shopping. Therefore, the blind are first of all interested in the lower denominations, i.e. the notes they receive as change in cash transactions.

Figure 45

ATM adapted for thee blind

Detail Braille text

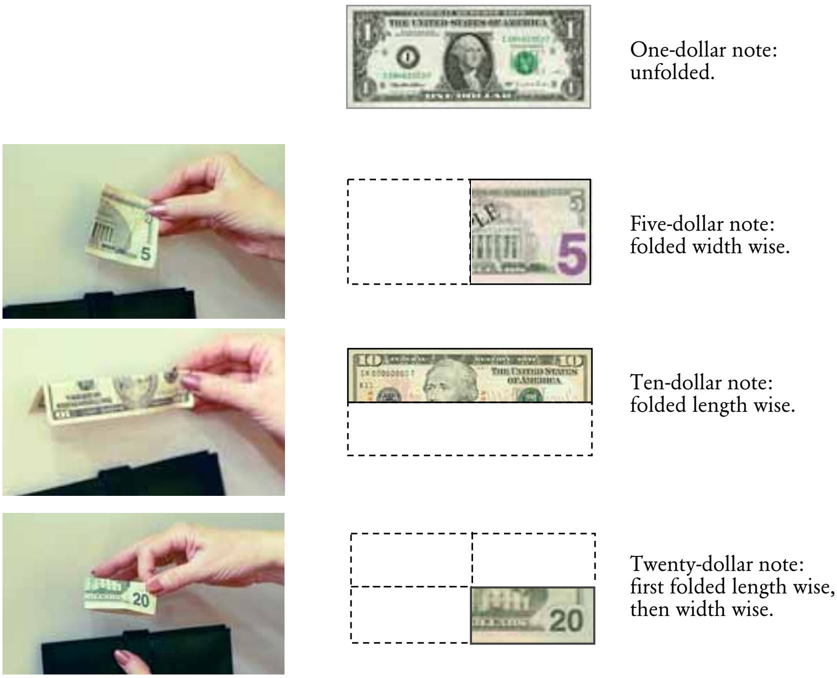
A table height position makes the ATM accessible from a wheel chair. The machine includes Braille texts and an audio jack. Picture taken by author at Washington Dulles airport in 2006.

Blind people may take banknotes – e.g. euro 50 – safely out of a cash dispenser or from their bank. ATMs have an option to specify the preferred denominations. Today ATMs on busy locations are being adapted to the visually impaired, as is shown in Figure 45. Clearly the USA is making more progress here than The Netherlands.

Later at home the blind may prepare the notes by folding them in meaningful quadrants (see Figure 46). Over 60 % of the Dutch blind said in 1986 that they are 'partitioning their wallet' with different denominations [24].

Advice EBU
For euro banknotes, the EBU recommends using a wallet with three compartments and storing all denominations beginning with the same digit in the same compartment (one compartment for the 5, 50 and 500 euro notes; one for the 10 and 100 notes and one for the 20 and 200 euro notes [95].
The efficiency of this system would be enhanced if the 5, 50 and 500 would all receive the same height, just as the 10 and 100 and the 20 and 200. Since not many blind will have a 100, 200 or 500 euro banknote, each wallet compartment might also be used for storing respectively the 5, 10 and 20 euro. A fourth compartment would be handy to store the 50 euro. The blind would be served most with clear distinguishing marks between these lower denominations.

Figure 46



Method taught by the American Foundation for Blind Vision. Fold each denomination in a distinct fashion: leave singles flat, fold USD 5 bills like a book, fold 10 bills lengthwise, and fold 20 bills in quarters. The different denominations are best kept in different partitions of the wallet.

Banknote acceptors: single note height

People, also the blind, will experience problems or delays when feeding the different note widths into banknote acceptors. The euro notes must be positioned in the middle of a slot or to the left of it (see Figure 47). People in Japan and the US will not experience such difficulties, since all denominations have the same height (Figure 48).

Stakeholders opt for a single note height

Compared to the Swiss banknotes currently in circulation, the future Swiss banknote sizes will lose 4 mm in height, going from 74 mm to 70 mm, and 40 mm in length, going from 110 mm to 70 mm. The Swiss central bank argued this measurement as follows: 'Banknotes will even better satisfy the current and future requirements with regard to machine processing. Costs can be cut at the production, packaging, storage and transportation stages.' [66]. Of course the Swiss will keep their single note height which is, as we have seen above, more efficient for handling banknotes.

Figure 47

Amsterdam 2005 | Frankfurt 2006 | Amsterdam 2009

The lack of uniformity of size between the various euro banknote denominations may lead to delays when people use banknote acceptors for their payments. This results in complex instructions. Pictures by author.
Left: Push the note forward and at the same time move the note to the left, Amsterdam: subway system (2005). Centre: Additional instructions appeared on the vending machines telling to keep a euro banknote in the middle of the slot when feeding it ('Banknoten mittig einführen'). Frankfurt: public transport system (2006). Right: Similar instruction as on the left. New public transport system, ready for 'chip card', Amsterdam (2009).

In fact all stakeholders would opt for a single note height, which is the trend world wide. The reason for this is clearly efficiency. ATMs and automatic banknote acceptors operate easier if a single banknote height is used. Both machines were introduced at the end of the 1980s and grew spectacularly in 1990s. And there are more drivers to a single note height, like uniformity of devices to check banknotes on counterfeiting, uniformity of cash register for the retailers or easier use of banknote sorting machines used by the central banks. Finally a single note height also

Figure 48

Washington 2006

Dollar banknotes are easily fed into a banknote acceptor because of the USD standard note height. Picture of vending machine by author (2006).

facilitates the banknote production: boxes, pallets and automated quality inspection are more efficient if there is a single note height (Figure 49).
Also the graphic designer would opt for a single note height, because of scaling problems with the design. However, there is one exception: the blind. The only reason for varying both banknote length and height is that this measure will benefit the blind (if large enough!). In section 5.3, Large length increment, it will be argued that today the differences between banknote sizes are too small to discriminate. The blind would be helped with a large increasing length increment. Doing so, a standard note height can be kept or introduced for efficiency reasons.

Notes should fit in standard wallets
If a single note height is adopted, what size should it be? From a customer point of view, this height is set by our wallets. In their 1999 brochure the Bank of Israel reports about the new dimensions of the banknotes: 'They are narrower than the first NIS series so that they do not protrude from the average size wallet, thereby reducing wear and tear.' [47]. The central banks of Malaysia and South Korea also issued smaller banknotes – respectively in 2005 and 2006 – using similar arguments like 'easier handling'. The South Korean 5,000 Won banknote has a surface reduction of more than 40 %. As said, the Swiss will decrease their note height from 74 mm to 70 mm. 'With their proportions being more ideal, the banknotes will not only give a more favourable overall impression, but wear and tear in the wallet can also be reduced' are the Swiss arguments.

Figure 49

Pallet with euro banknotes

Banknote sorting machine at DNB

A single note height is more efficient for banknote handling.
Left: Pallet with euro banknotes. Carton boxes and pallets can be uniform with a single note height.
Right: Banknotes with a single note height are more efficiently processed by banknote sorting machines, like this CSI-machine at DNB, Amsterdam (2005).

Following these trends and some additional research to wallet sizes, the conclusion is that an optimal note height for European wallets is between 65 and 75 mm [74]. Most logical would be to use the note height of the euro 20, being 72 mm, as the standard for a new series of euro banknotes. This size fits perfectly into our wallets and is already used daily.
In 2009 three experts on wallet design confirmed this finding. They concluded that the euro 50 banknote (height: 77 mm) does not fit properly in modern American wallets, like the so called 'billfold' type. The reason is the larger height of the euro 50 compared to the US-dollar' [101].

Sizes of euro banknotes
The euro banknotes do not properly fit in the Dutch wallets, is a remark heard. Because of such and other remarks like 'the euro 5 is so small' DNB invited the Dutch to give their judgement on the sizes of the euro banknotes as part of DNB's bi-annual public opinion poll in 2009. The outcome was clearly that the size of the 20 euro banknote (height 72 mm) is the most accepted; 94 % of the respondents judge these sizes as 'exactly correct'. Also the size of the 10 euro banknote is accepted by 92 %.
Many have no opinion on the sizes of the high euro denominations (100, 200 and 500). Those with an opinion about these denominations are divided: around 50 % accepts the sizes, while the other half judges these notes as too large. The euro 50 banknote is too large for 21 %, while the size of this note is accepted by 76 %. Youngsters consider the high-value euro banknotes (50 and above) more often too large compared to the elderly. The size of the 5 euro banknote is accepted by most respondents, although a large part, 25 %, judges this note indeed as being too small [102, 105].

5.3 Large length increment

Varying the banknote sizes seems to be the oldest feature to discriminate different banknotes on their face value. Appendix 4 provides an overview of the history and

Table 11

	5	10	20	50	100	200	500
Height (mm)	72	72	72	72	72	72	72
Length (mm)	124.0	131.0	138.3	146.0	154.2	162.8	171.9
Δ L (mm)	7.0	7.3	7.7	8.2	8.6	9.1	–

Optimal dimensions for a banknote series, based on a first length increment of 7 mm and a starting length of 124 mm. These values indicate a Weber fraction of 0.056.

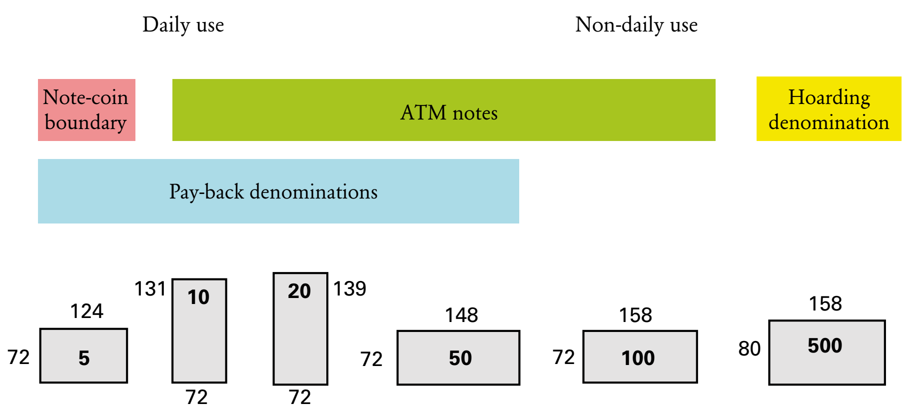
recent trends of banknote dimensions. Analysing its history leads to two conclusions:

- banknote sizes have become too small for a reliable denominating process,
- if banknote sizes should vary, a single note height with a large length increment is the best solution.

If a length increment is used, it is often a regular system; the banknote length increases with a fixed figure like e.g. + 6 mm in case of the former NLG-notes. In case of the euro banknotes the length increment is irregular: 6 or 7 mm. Both systems, regular and irregular, can be improved by using the principle of an increasing length increment, following the Weber law (1834). If two small banknotes are compared to each for their length, a small length increment will do. Larger banknote lengths need a larger increment is what Weber's law predicts. This principle is explained in Appendix 5. Based on a Weber fraction of 0.056 a set of banknote dimensions are developed in Table 11, introducing a standard note height of 72 mm.

Based on the figures in Table 11 a new banknote series may be developed as is shown in Figure 50. Extra attention is given to the denominations the blind will receive as change (or pay-back denominations). Also the other denominations are marked from such a user's point of view. A very first proposal along similar lines was made by De Heij and Stange in 2006 [74].

Figure 50



Example of an innovative concept for the dimensions of a series of banknotes. Two categories of note heights: one for daily use in wallets and banknote acceptors (single note height for 5-10-20-50-100) and the other for large-value payments and/or hoarding money (500). For the blind the pay-back money (5-10-20 and also in the future the 50) are the most important denominations. The 200 has been left out since this is not an ATM-note and is also not used for hoarding. The 10 and 20, i.e. the most important lower denominations have portrait orientation for people with low vision. The hoarding denomination might have a large note height to provide space to additional security features.

Figure 51

Tactile marks in Swiss notes

Tactile marks in Israeli notes

Two examples of blind marks that are not continued.
Left: The Swiss central bank reported in 2005 that 'we are currently assessing the technical implementation of different solutions and will contact the appropriate associations in due time.' [66]. Design: Jürgen Zintzmeyer, first issue in 1994.
Right: Second Series of the NIS, introduced in 1999 with blind marks. These marks have been left out in the 2008 polymer upgrade. Design: Naomi and Meir Eshel.

5.4 Different tactile structure on each denomination

Once the central bank has realised banknote formats suitable for both an efficient banknote circulation (standard note height) and helpful to the blind to assist denomination recognition (large, increasing length difference), a second requirement is needed for the blind, since banknote dimensions alone are not a reliable denominator.

New intaglio engraving systems
With the new intaglio techniques this second feature is a tactile structure on all denominations. Around the year 2000 new intaglio engraving systems became available. Plate making could now be done by drilling (mechanical system) or laser engraving instead of chemical etching. These new technologies increased both the security and the quality. A general overview of the product and production specifications is given in Appendix 10.

Blind marks are not helping and are abandoned
The first dedicated printed feature for the blind was issued in 1971 with the introduction of the Dutch NLG 10/Frans Hals. One of the many innovations of this note

is the introduction of a special code (3 dots) representing the denomination (10 guilder). The term 'blind mark' was born (in Dutch 'blindenteken'). A blind mark is a dedicated symbol printed on banknotes, especially to be used by the blind to denominate the banknote. The history of the marks for the blind and braille like features is described in Appendix 6.
To date central banks leave this feature. The Dutch moved from single tactile marks to tactile structures in 1992 (see Appendix 7). In Indonesia the blind mark was left out in their 2004 banknote series. The marks were also abandoned in 2008 on the redesigned polymer NIS-notes, after there introduction in 1999 (Figure 51). The single blind mark on the present Swiss notes – first issued in 1994 – will most probably be replaced by a different solution in 2010.

First results new intaglio engraving techniques
The new engraving techniques are already used for tactile elements on banknotes. The first printing results were presented in 2005 by Professor Huber Dinse (Figure 52). The study explored the possibilities of the so called Computer to Intaglio Plate (CtIP). This study was sponsored by the banknote industry (KBA, Sicpa and Giesecke & Devrient). The height of the elements in this study was 100 microns. Dinse reported:

- Height of intaglio profile for secure identification (new samples) > 75 +/-5 µm (or micro millimeter or micron).
- Geometrical feature (edges, size, frequency, accuracy) of pattern play a significant role for reliable recognition.
- Closing a group of tactile elements with a printed line might impair the identification.

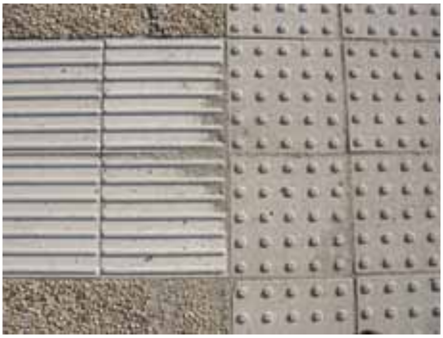
Basic principle of tactile structure
What matters for a banknote series is that denominations next to each other can be distinguished.
Using the short and long side as one of the design parameters to come to a codification system will reduce the complexity of the tactile structures on each denomination. A pattern based on lines could be used on one denomination along the short edge and one other along the long edge. Doing so is not enough to cover 6 or 7

Figure 52

Tactile elements made with new intaglio engraving techniques (CtIP) and tested by Professor Hubert Dinse in 2004 - 2005 [67].

Figure 53

Street tiles using lines and dots



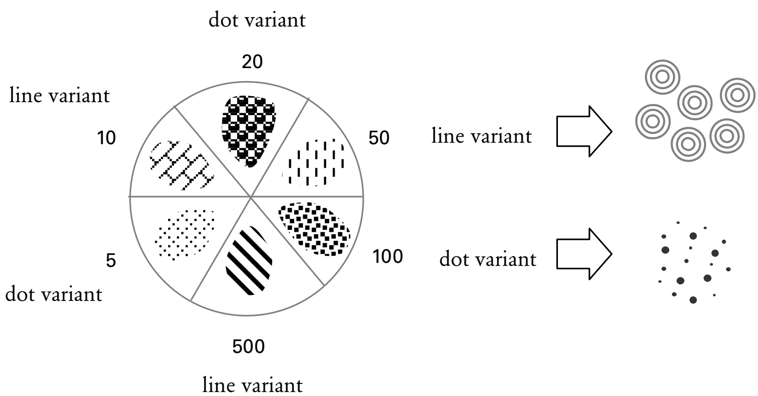
Dots mark a junction

Public transportation in the Netherlands is accessible to the blind and poor-sighted. Street tiles with parallel lines are used to guide the blind. Dots mark a turn. The strong relief is detected by moving the white stick left-right and/or felt through the sole of the shoes. The bright tiles also points the way to people with low vision. Photographs taken by author at Santpoort Zuid railway station in 2008.

denominations. Next to lines, dots could be used, analogous to the street tiles used to guide the partially sighted and blind (see Figure 52).

The generic element on which the tactile structures are based should alternate lines and dots between successive denominations. Seven patterns could be drafted using these two design parameters, long-short edge and line-dot variants, as is shown in Figure 54.

Figure 54



Different patterns enabling discrimination between consecutive banknotes on the basis of dots or lines. The variants should be as different as possible, using different dimensions and spatial frequencies. One dot and one line variant have been worked out in more detail by way of example (not to scale). Concept by author.

General requirements for the tactile patterns for the blind
Analysing the information provided in Appendix 6 we may list the following design requirements to specify the tactile patterns in more detail:

- All denominations should have a tactile structure.
- All denominations should have a denomination codification, using the tactile structure.
- The tactile structures may serve as a security features to all people.
- The tactile structures should not attract the human eye. Integrate the structures into the design to prevent stigmatizing.
- Location: alternate between the long and short edges of the note.

- The generic pattern for the tactile structure on each banknote should be based on either dots or line elements.
- The width of the (unprinted) areas between the elements should not be too narrow. There must be enough space for the finger tips between the lines: spacing > 1.5 mm.
- Orientation: the tactile pattern should have one tactile direction (like the nap of velvet).
- Colour: in principle free. To make the marks not too visible there is a preference for the same intaglio colour as offset underground or a colourless intaglio ink.
- Height: an ink height of around 0.1 mm is possible (printing method: new digital engraving techniques like for example CtIP).

- Steepness: the elements of the texture (or marks) should be as steep, as sharp as possible. With the new CtIP technique the steepness of the lines/dots can be increased.
- Geometry: keep motifs simple. Use triangles, squares, rectangles, circles, rhombus, simple stars etceteras.
- Concentric/parallel patterns increase tactility sensation.
- Blind people tend to get confused with multi-side polygons (more than 4 sides).
- Printing surface: Printed on a smooth surface (foil, plastic) the relief is better detected as on the rougher surface of cotton banknote paper. Printed on an offset or silkscreen underground the smoothness is higher than when printed directly on the cotton paper.

Requirements to a generic pattern based on dots
In case of dots the generic pattern should be constructed of:
- Dot diameter: varying between 0.1 mm and 0.5 mm.
- Space between the dots: varying between 0.6 mm - 1.4 mm.
- Number of elements: > 10 (the more the better).

Requirements to a generic pattern based on line elements
In case of a generic pattern constructed from line elements:
Line widths: 0.2 mm - 0.4 mm.
- Line separations: 1.2 mm - 1.4 mm.
- Tactile sensation is increased when the lines are (partly) interrupted or broken.
- Number of elements: > 5 (the more the better).

Tactile codification within large numerals
Why don't we give the large numeral a tactile structure? This idea may be heard during design meetings and is a logical argument, since sighted and blind people would use both the same denomination feature, the numeral. An advantage is also that the numerals are already codified, so the tactile pattern does not need further denomination codification (although this will make the denomination feature more redundant).
There are two such design examples known, the Dutch guilder and the Canadian dollar banknotes (Figure 55). The outline of the large numerals on the guilder banknotes was printed in a thick intaglio line. The human finger fitted in between the two outlines and could follow – like a tram on rails – the numerals. In case of the Canadian dollar banknotes people may feel the tactile pattern within the numerals. This pattern is about identical for all denominations.

How do people take banknotes?
In case of a tactile area one of the questions for the central bank and its designer is: which area of the note would the blind prefer; the top, bottom, left or right side of

Figure 55

Large numeral in outline

Large numeral also tactile pattern

Two examples of tactile codification in the numerals of the banknote.
Left: NLG 25/Robin, issued in 1990. The large 25 (30 mm!) in the centre is printed in outline using the thickest relief possible. With your finger in-between the 'rails' you could 'read' the numeral.
Right: Redesign of the CAD 10, issued in 2004. The large 10 numeral is filled with a highly tactile pattern. Disadvantage: reduced contrast for the partially sighted compared to the 2001 original.

the note? By nature people take spontaneously the boundary of banknotes at hand. It is logical to place tactile structures in these areas.

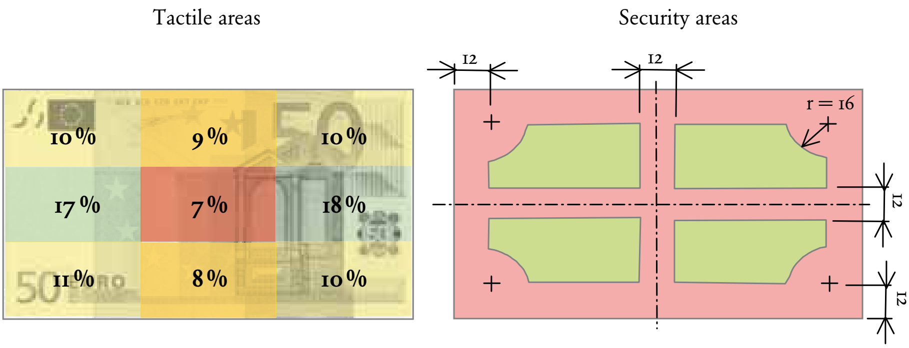
The ECB ordered in 2006 a detailed study to such human behaviour. The middle portions of the short edges of the banknote were touched most frequently, the green areas in Figure 56 (image on the left). The green areas in the image on the right of Figure 56 are optimal for security features. Fortunately these areas are more-or-less complementary to the optimal areas for touch!

Analysis of touch

The hand sensory quality of banknotes depends on several parameters like the basic tactile signal, the temperature of the fingers and the temperature of the environment. Other parameters are the position, force, pressure and velocity of the movements of the fingers and the cognitive processes that control them. People with less tactile feel in their fingers, like diabetics and the elderly, will experience a reduced tactile signal or none at all even. At an older age the skin is less sensitive. Also learning to use the touch senses is more difficult for the elderly.

In the case of a banknote, the signal also depends on the banknote's condition. Relief on limp banknotes will deliver a reduced tactile signal. Crumples in a banknote can be seen as a signal noise disturbing the original tactile signal of the relief. From Dutch studies conducted in 1983 on the durability of intaglio ink on banknotes, it may be concluded that the ink layer on worn-out notes is about the same as on new, fresh printed banknotes. Relaxation of the paper fibres is the main reason for the lower note relief height [14].

Figure 56



The optimal tactile areas match to a larger extent with 'no go' areas because of folding lines and dog ears.
Left: Relative frequencies of touches of the front of the 50 euro [78, 88].
Right: Optimal areas in green for security features as used for design of NLG-notes [48, 86].

Haptic banknote design
Feel features on banknotes could also be called haptic features. Today we may hear this new expression: 'haptic banknote design'. The human sense of feel is much broader than purely tactility. Tactile perception is restricted to studies on skin (or cutaneous) stimulation and does not include the grip and movement of muscles and limbs, the field of kinaesthetic perception. When (normal sighted) people look at a banknote and start touching it, there is an interaction between the visual and tactile perception. Touch and vision are processed in different parts of the brain. Touch is primarily processed in the somatosensory cortex. The visual component of the touch is processed in the visual cortex. Haptic perception is the study on the joint perception of both tactile and kinaesthetic perception.

In a test with banknotes professor Dinse reported that vision can dominate touch: 'when vision and touch were used simultaneously to examine the same stimulus, and visual information was adequate for responding, vision dominated touch' [99]. However, for the blind the visual part is absent. For people with normal vision this promotes a tactile pattern based on 'silent design', e.g. using transparent intaglio inks (NLG-notes) or using the same intaglio colour as the (offset) background.

There are more ways to gain the public attraction than purely tactility like relief. Think of smooth-rough, stiff-flexible and nail scratch elements producing a sound [73, 81]. Also the way in which people take a banknote is a research parameter. Often there are four fingers on the reverse side and the thumb on the front. And especially the very first moment of taking a banknote seems to trigger the receiver to pay attention to the just received note.

5.5 **Smooth – rough**

So far we have realised two denomination features for the blind (large, increasing length increment and tactile codification). One more feature is required for the blind: an orientation feature. The blind would like to know: What is the front when feeding banknotes in an acceptor or storing notes in my wallet? And: what is the left and what is the right side? Central bank and designer could use here a so called 'smooth-rough' parameter not yet used for denominating banknotes. The Dutch blind recognised the smooth area on the NLG 100 issued in 1993 and used it as an additional denomination feature (Figure 57). Such a smooth foil feature will also help the blind to orientate the banknote: the smooth area is on the front and is the left side of the note (in case of ATS 5,000) or the right (in case of NLG 100).
Figure 58 is a first concept of a further exploration to use smooth-rough through a banknote series design. A smooth front is combined with a rough reverse (or vice versa).

Figure 57

First foil in banknote

Second foil in banknote

Left: ATS 5000, first banknote with a smooth element, a foil patch (1989).
Right NLG 100/Little Owl, second banknote with a foil patch (1993).

5.6 Check against user requirements

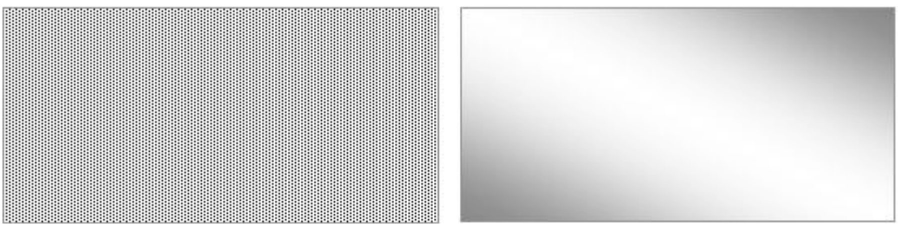
Table 12 is a tool to check if the designed features meet the user requirements in this case scored for the euro notes. Due to the peculiar sizing of the euro notes, the quality of the different dimensions of the euro notes is set at neutral for several user requirements. As a consequence the scores for the euro banknotes are suboptimal. Since the tactile area with codification is only featured on the 200 and 500 euro notes, the other notes do not incorporate two full denomination features for the blind.

Blind close to a visual equity of 6/60 metre might profit also from the features for the partially sighted like e.g. the large numerals. These features are described in Chapter 4. The totally blind will not profit from any of the other features first of all dedicated to the partially sighted.

Figure 58

Rough front

Smooth reverse



Front – reverse: smooth – rough or vice versa.

Table 12

User requirements BLIND	Features to assist the blind with denominating different euro banknotes: Feature 1 — Length increment > 6 mm Increasing + 1 mm	Feature 2 — Tactile area with codification
1. Denomination time < 3 seconds	–	+
2. Reliable denominating	–	+ +
3. On low denominations (pay-back notes)	0	– –
4. On all denominations	0	– –
5. No assistance needed	0	+
6. No additional tool needed	0	+ +
7. Discretely	0	+
8. Standard (position) front	+ +	0
9. Standard (position) reverse	+ +	na
10. No training needed	–	0
11. General quality of feature	0	–
Central bank		
12. Long-wearing	+ +	0
13. Difficult to simulate	– –	0
14. Inexpensive use	– –	+ +
15. Low cost for producer	–	+ +
16. Low social cost	– –	+ +
17. Non destructive to banknote	+ +	+ +

Overview of the user requirements of the blind and the features to assist the blind denominating different euro banknotes. Requirements 12 - 17 are coming from the central bank. Scored by author.
na = not applicable.
+ + = yes, very good, + = yes, good, 0 = neutral, – = poor, – – = very poor.

5.7 Synthesis: new banknote concepts for the blind

Figure 59 is an innovative proposal for a series of banknotes. This concept, from which the 200 euro denomination has been left out, is based on large and increasing length increments for the lower-denomination notes, based on an average Weber fraction of 0.06. Starting with a length of 126 mm this will lead, rounded off, to a logical sequence of increasing length increments for successive denominations, respectively 7, 8, 9 and 10 mm (Table 13).

Table 13

	5	10	20	50	100	200	500
Height (mm)	72	72	72	72	72	72	72
Length (mm)	126	133	141	150	160	160	171.9
Δ L (mm)	7	8	9	10	–	–	–

Optimal dimensions for a banknote series, based on a first length increment of 7 mm and a starting length of 126 mm. These values correspond with a Weber fraction of around 0.06.

The second denomination feature is a renewed and increased tactile pattern on all denominations. The denomination codification of this tactile structure is twofold: it alternates along the long and the short edges and comes in different tactile patterns (e.g. dots, pins, chevrons). An improvement is also the tactile structure, using new intaglio printing techniques as for example CtIP. With this technique, the printed elements can be increased in height up to 100 µm (0.1 mm). Contributing even more appreciably will be the increased steepness of the printed lines.

Innovative tactile features for the blind

So far, tactile features on banknotes have been based on relief: dimensions, shape and texture. The printing technology has always been intaglio; except for the tactile mark in the paper of the former Japanese Yen banknotes (see Figure A6.7 in Appendix 6). Innovative features could be created by using other design parameters like smooth/rough, softness and thick-thin.

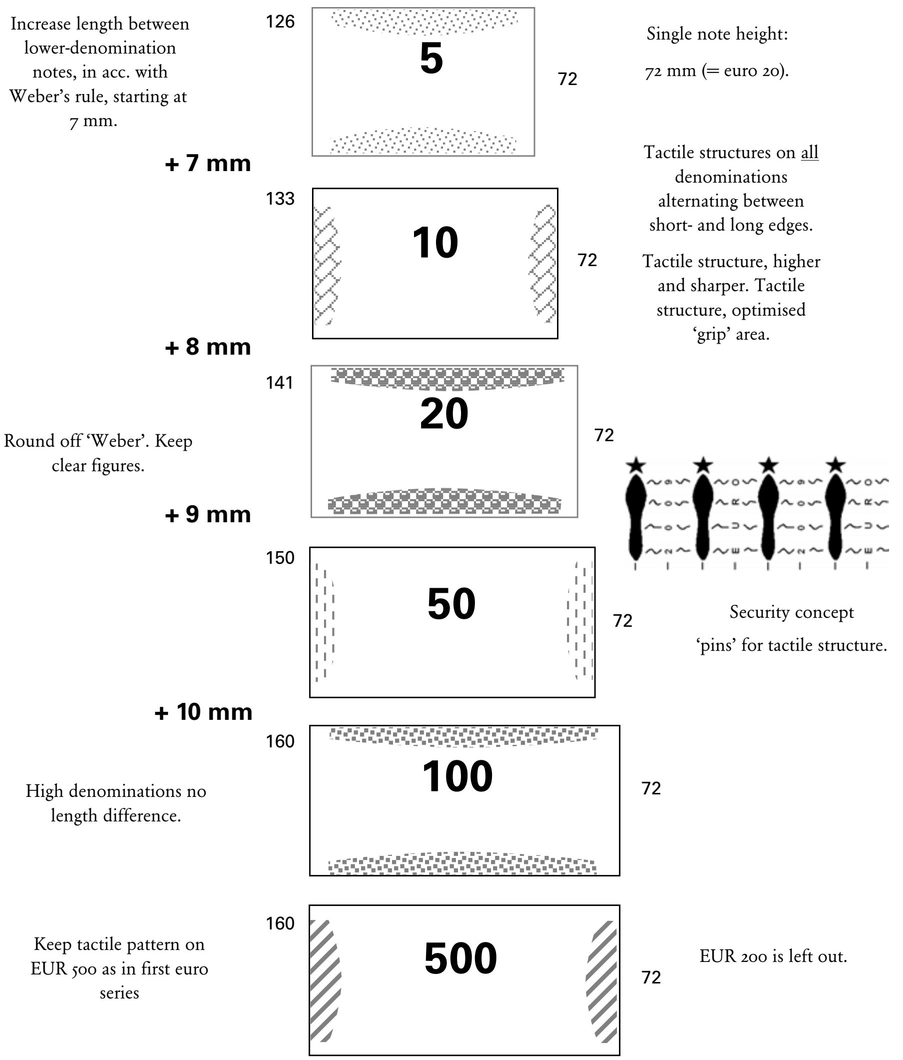
Today almost every security paper machine uses two layers. In between these layers thin metal or plastic elements could be incorporated, as De Heij and Koeze proposed in 1988 (see Appendix 9). This is in line with suggestions of the European blind to use more durable materials such as wire or plastic to create tactile features [38]. In 2007, a similar idea was mentioned in another, recent report of the National Research Council. They suggested a compositional change of the substrate to incorporate new materials in a variety of innovative ways, e.g. paper-embedded tactile denomination markings that 'appear on demand' when the note is stretched [85].

Until today none of such innovative ideas were worked out successfully enough to be considered suitable for banknotes.

5.8 Historical overview

Once more a short overview of the banknote history of the first introduction of special banknote features for the blind is provided at the end of the relevant chapter

Figure 59



Conceptual proposal for a combination of sizes and tactile structures for euro banknotes. Length differences according to Table 13. Starting point for the tactile system for the series is the tactile structure of the existing euro 500. Different tactile patterns alternate between short and long edges. An example of a secure tactile structure – named pins – is also provided. The security is found in the thin lines and micro-text; today such combination of enhanced tactility and high resolution elements is possible using the new intaglio engraving techniques (see Appendix 10, New intaglio engraving techniques).

(Table 14). Since this history has never been recorded, a bias on the Dutch banknote design is possible. Before 1900 banknotes were not much used by the public. Since around 1970 the innovations happened in rapid succession.

Table 14

BLIND

WHEN	BANKNOTE	WHAT IS NEW?	BY
1824	-	Invention Braille script.	Louis Braille
± 1850*	several series	Different lengths and widths within series.	several central banks
1961	DEM-series	Systematic length (10 mm) and height (5 mm) differences between 7 denominations	Bundesbank
1971	NLG 10 Frans Hals	Standard note height of 76 mm because of mechanic sorting (length increment 6 mm).	De Nederlandsche Bank
1971	NLG 10 Frans Hals	First banknote with system of dots for the blind. Three dots in intaglio print, Ø 5 mm.	De Nederlandsche Bank
1976	CHF 100 Borromini	Second central bank with 'code for the blind'.	Swiss National Bank
1980	USD, study on codifications	Corner cuts, edge notches, holes.	US, Bureau of Printing and Engraving
1982	NLG 50 Sunflower	Single special mark: triangle shape. Based on (limited) investigations with the blind.	De Nederlandsche Bank
1984	JPY 1.000 Soseki Natsume	Doughnut shaped element in paper, Ø 5 mm. Abandoned in 2002 for marks in intaglio.	Bank of Japan

BLIND

WHEN	BANKNOTE	WHAT IS NEW?	BY
1986	CAD Birds of Canada	Bank Note Reader reads bar code and tells denomination. Device came in 1989.	Bank of Canada, Brytech
1986	NLG 250 Lighthouse	Double line (in single special L-shape mark, based on response of 5 blind persons).	De Nederlandsche Bank
1987	NLG, notes in circulation	Large scale experiment. 40 blind people tested real and test notes. Including opinion poll.	De Nederlandsche Bank, TNO [24, 26, 29]
1988	NLG	Proposal for special mark into the paper (like e.g. a thin metal or plastic element).	De Nederlandsche Bank [22]
1990	NLG	Design plan tactile structures on new NLG notes.	De Nederlandsche Bank, Jaap Drupsteen [30]
± 1992	Austria, Italy, Germany	Introduction CashTest. Plastic device to translate note lengths into high tactile symbols.	Caretec
1992	NLG 100 Little Owl	Special texture, dots, Ø 1 mm (based on respond of 5 blind persons).	De Nederlandsche Bank
1995	USD study	Study ‘Currency features for visually impaired people’.	National Research Council, USA [37]
1995	EUR recommendations	Brochure ‘Currency design for visually impaired people’, recommendations for euro.	European Blind Union [38]

BLIND

WHEN	BANKNOTE	WHAT IS NEW?	BY
2001	CAD 10	Introduction 'tactile feature'; Braille like clusters of six raised dots. These dots are embossed and back-coated. Height: 110 µm.	Bank of Canada [56, 79].
2001	EUR	Trainer kits with dummy notes of euro banknotes. Blind may learn new series.	European Central Bank
2003	Study Digital engraving systems	Tactile marks based on new technique (CtIP).	Hubert Dinse, research ordered by banknote industry [67, 99]
2006	PKR	Off running tactile areas.	National Bank of Pakistan
2006	USD	Judge tells USD notes are not assisting blind.	US Court
2009	USD	Study various aspects use USD-notes by blind (and partially sighted)**	ARINC for US Bureau of Engraving and Printing [106]

*) In the Netherlands two different sizes were introduced in 1859. Low denominations 220 mm × 105 mm (NLG 25, 40 and 60) and high denominations 220 mm × 120 mm (NLG 100, 200, 300 and 1,000).
**) This study became available in July 2009 when the first printing proof of this Occasional Study was already made.

Milestone overview of the development of recognition of banknotes by the blind.
Above the dotted line are features that are already suitable for use by the blind, but were not intentionally designed for the blind.

6 Conclusions

6.1 **General**

6.1.1 Currency features for the visually impaired are the result of trial and error rather than pro-active dedicated research by central banks. Often the result is not very satisfactory.

6.1.2 Be wary of 'research' results concerning the visually impaired and especially the ones on the blind; they are often based on trial and error and are quite often 'quick and dirty'.

6.1.3 Central banks, although just a few today, are becoming more pro-active in developing features for the visually impaired.

6.1.4 In banknote design, central banks observe different policies for the visually impaired. It is also clear that there is confusion about the requirements.

6.1.5 The banknote has a limited size and is increasingly crowded. Features for the visually impaired compete for space with security features which are essential to protect all users from counterfeiting.

6.1.6 The use of features for the visually impaired needs to be compatible with maintaining the performance of banknotes in other respects, such as security, durability, and environmental responsibility. Banknotes also have to meet the needs of a broad range of users, including the general public, retailers, cash handlers, machine processors and the police.

6.1.7 Visually impaired persons, whatever their nationality or culture, all have similar needs. A solution that works for one culture or nationality, will therefore automatically also work for another. The research conducted in this field by one central bank, will therefore also be useful to any other central bank.

6.1.8 The visually impaired, while no designers or product developers, can formulate user requirements from their perspective. These requirements should be translated into design requirements (by the project manager of the central bank). A creative banknote designer will come up with satisfactory solutions.

6.1.9 Issue no more denominations than are used in daily cash payments. Limit the high denominations to one.

6.1.10 The amount of elderly people is expected to increase in the future. The percentage of people with eye problems, like low vision and blindness, will increase accordingly. This prospect is an additional reason for banknote designers to pay more attention to these stakeholders.

6.1.11 A good design for the blind and partially sighted is a good design for everybody.

6.1.12 Two features are needed for every subgroup of the visually impaired to establish the banknote's value; one is not reliable.

6.1.13 Verify the quality of the designed banknote by having it tested by the visually impaired. Test complete series or the part used in daily cash payments like ATM-denominations and pay-back notes. Do not test individual notes. Include the other denominations of the series (or banknote circulation) within the test.

6.1.14 Since around 1950, a trend towards smaller banknotes and a larger number of denominations has been perceivable. As a result, since around 1990, the differences between successive banknote values have become too small to enable denominating banknotes on the basis of size alone.

6.1.15 Both length and width differences between banknotes have decreased over the decades. Today these size differences (especially in width) are too small to serve as reliable banknote denomination features for the blind. As a result, blind people only incidentally check a note's height to denominate its value.

6.1.16 Only the blind use the banknote sizes as basis for denominating banknotes. The partially sighted and the colour-blind use other features like colours and numerals. Up to date, the blind would be helped better, climbing up the denomination scale, with large and increasing length differences between successive banknotes. The height of the banknote can be fixed the same for all denominations that are used in daily cash transactions.

6.1.17 A standard note height is required by society because of:
- regular wallet sizes,
- banknote acceptors and ATMs,

- banknote production, including logistics (e.g. boxes, pallets),
- banknote sorting (e.g. high speed banknote sorting machines),
- banknote handling (e.g. cash register of retailer).

Also to the blind a single note height is preferable because of the use of the CashTest.

6.1.18 Design parameters for coin denomination features are diameter, edge profile (shape), edge milling and holes. For banknotes, the most popular parameters in this context are colour, relief and banknote length.

6.1.19 The denominations within the euro banknote series can not be reliable denominated by the blind. Also the colour-blind and partially sighted experience hesitation establishing the note's value. For all visually impaired the denominating process will be improved if the 200 euro could be left out from the next series.

6.2 Colour-blind

6.2.1 Good banknote design for the colour-blind starts with a well-considered colour wheel for the full series. The colour of any new banknote design can be improved for the colour-blind if the colour scheme is tailored to them.

6.2.2 The general impression of the design should be monochrome. Additional colours may be added, but should not be dominant.

6.2.3 Use bright, saturated colours, keeping the use of shades to a minimum. The colour of the note should be evenly distributed across the whole surface.

6.2.4 Next to colours, the colour-blind use the large numeral and the different silhouettes to denominate a banknote.

6.2.5 What works as design for the colour-blind, need not be attractive for the public at large. Nevertheless, a banknote designer should start from the colours that are optimal for the colour-blind.

6.2.6 In the case of the euro banknotes, the colours of the green 100 and the purple 500 had better be swapped. In other words, the EUR 100 should be purple and the EUR 500 green. However these denominations are not used for daily payments.

6.2.7 The present design of the euro banknotes falls short when it comes to accommodating the colour-blind. Especially the magenta of the 10 euro banknote and the orange of the 50 euro note might be more vivid (brighter). The 500 euro is improved if its purple would be more intense.

6.3 **Partially sighted**

6.3.1 The design of the numerals and their backgrounds should be based on human factors research regarding contrast, positive/negative prints, font and background design. The numerals should be free from any other design element.

6.3.2 The partially sighted are best served with large numerals. The numerals should be at least 15 mm high (the preferred height is 22 mm).

6.3.3 Besides the numerals, the partially sighted use the main colours and the different silhouettes in the new banknote series design to determine a denomination. Also additional geometrical figures could be useful for denomination recognition.

6.3.4 Images on the euro notes do not contribute to instant value recognition for people with low vision. Their images are mutually replaceable as long as the main colour of the denomination is maintained.

6.4 **Blind**

6.4.1 First of all, banknotes should enable the blind to identify the value of the notes they receive in return in a cash transaction. In the case of the euro, these notes are the EUR 5, 10 and 20 notes.
Secondly, while also the higher denominations should be provided with denomination features for the blind, priority should be given to the lower denominations (e.g. length increments between consecutive lower denominations only).

6.4.2 The conclusion that banknote sizes varying by denomination are the most valuable feature for the blind needs to be put into perspective. Most blind appear indifferent between a system based on only length differences or a system using both length and width varieties. However, for the blind to be able to denominate banknotes, it is not necessary that both length and width are increased between two consecutive denominations. Varying on just one dimension suffices, providing that the size increment is sufficiently noticeable. Because of the average wallet size, varying on banknote length would seem the most practical, since larger height increments will result in banknotes protruding from wallets.

6.4.3 Larger banknote lengths need larger length increments. The length increment should not be a fixed figure (e.g. 7 mm), but increase with the value of the banknote. More human factors research will be required to arrive at the optimal (mathematical) function. Before that stage is achieved, the Weber fraction should be followed.

6.4.4 A Weber fraction of 0.03 of a lower limit to length differences for banknotes was recommended by the NRC committee [37]. It seems that this lower bound should be set higher, at least at 0.06. Going up the denomination scale this Weber fraction would lead to an increase of the length differences between consecutive denominations of + 7 mm, + 8 mm, + 9 mm and so on (at a starting length of 126 mm).

6.4.5 The same holds true for banknote heights. Height increments for the blind are not effective unless starting at a minimum of 6 mm per denomination.

6.4.6 A high increment is not advised because of regular wallet sizes and the CashTest device. Furthermore it is blocking banknote efficiency in logistics.

6.4.7 A standard note height for a banknote series should be between 65 - 75 mm. A standard note height for a new series of euro banknotes is advised at 72 mm, being the present height of the euro 20.

6.4.8 Single blind marks, a solitaire symbol like a dot or triangle, are ineffective. Such single marks are not required by the blind. Such symbols are serving more publicity tool of the central bank rather than an adequate solution for denominating banknotes.

6.4.9 Single blind marks should be avoided; instead, tactile structures are more helpful to the blind.

6.4.10 In a banknote series, the tactile structure should contain a codification to assist the blind in the banknote denominating process.

6.4.11 Tactile structures for the blind should not be obvious as they may be considered stigmatic and patronizing.

6.4.12 Tactile structures should be positioned in the banknote areas that people touch most often, i.e. not in the corners or on the vertical central folding line.

6.4.13 Banknote codification should be based on a 'generic tactile element'. For each denomination such elements should be as different as possible.

6.4.14 Generic structure should alternate between dots and lines.

6.4.15 Consecutive banknote denominations should alternatingly have a tactile structure along the long edge and the short edge.

6.4.16 The new digital engraving techniques will create new solutions/possibilities for tactile patterns, e.g. a higher relief (up to 100 microns), steeper lines (possible because of laser technology) and positioning up to banknote's very edge.

6.4.17 The euro banknotes as they are today are not the optimal solution for the blind. Especially the differences in height are too marginal to contribute to reliable banknote denominating. Secondly, the system used for the length increments is irregular and peculiar. Third, only the EUR 200 and 500 have a denomination code based on tactility.

6.4.18 Smooth-rough features are used neither for banknotes nor for coins, but could be introduced to provide an orientation to the banknotes. Doing so the blind would be able to feed banknotes properly into banknote acceptors.

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Appendix 1

Methods for adapting the colour of banknotes to meet the requirements for the colour-blind user

A1 Introduction

In 2005 De Nederlandsche Bank ordered the first colour-blindness study on new developed euro banknotes, in cooperation with – and paid by – the European Central Bank (ECB) [68]. This study on the so called 'Two Year Project' was done by Blind Color. In 2008 a follow up study was done on a new developed euro 50 banknote [87].

A modern banknote design is typically multi-coloured and may employ 10 to 15 different colours (or inks). For colour measurements the multi-coloured banknote needs to be transformed into one single colour. The method developed and used is called the 'DoCol-method', short for Dominant Colour method. Manipulation of the DoCol is the most efficient way of making colour coding of the denominations of banknotes accessible for the colour-blind. Once the DoCols of a series of banknotes are known it is possible, by using the TNO colour-blindness-simulator [43, 44], to visualise how these will be perceived by people with deficient colour vision. One can thus identify the problems that may be encountered in distinguishing the different banknotes and try to alleviate these by intruding changes in the colour scheme. This is not easy, of course, because one should be careful not to make the design less functional and/or attractive for the majority of users with normal colour vision.

Three different approaches (but yielding the same outcome) have been used for the determination of the DoCol of a banknote. That is,
1) presenting a banknote on a computers screen with in its centre a digitally pasted square (10 mm × 10 mm) of which the colour can be manipulated in order to match it to the overall colour of the surround, i.e. the DoCol,
2) the same procedure but now with a real banknote with the test square cut out of the center and with a Pantone fan deck behind it to determine the DoCol,

3) making a digital grey-scale image of a banknote and then turn it into a monochrome banknote with a colour matching the DoCol of the polychrome original.

When a DoCol is established for the existing banknote and for the new design, the difference between two DoCols – representing two different banknotes – can now be expressed as a distance in an appropriate colour space (i.e. CIE-LAB).

TNO colour-blindness simulator
The next step is to see how the test note is perceived by colour-blind observers. The software of the TNO colour-blindness simulator includes a colour editor that can be used for obtaining the colorimetric specifications of any colour in a picture. These colorimetric specifications are transformed into the images as perceived by each of the four types of colour-blind persons (protanopic, deuteranopic, protanomalous and deutranomalous).

Test on complete series
Studies on colour-blindness should evaluate the complete new series (and not one or two notes).

A1.2 **Digital pasting and blurring (DoCol method 1)**

A square of 10 mm × 10 mm is digitally pasted in the centre of both the front and back of a euro 50 banknote. The colour of this square can be manipulated with graphics software (e.g. PhotoShop) for varying its hue (H), saturation (S) or lightness (L). It can thus be used to determine the monochrome colour of the test square, the DoCol, which visually matches the general impression of the polychrome

Figure A1.1

Square in blurred image front | Square in blurred image back

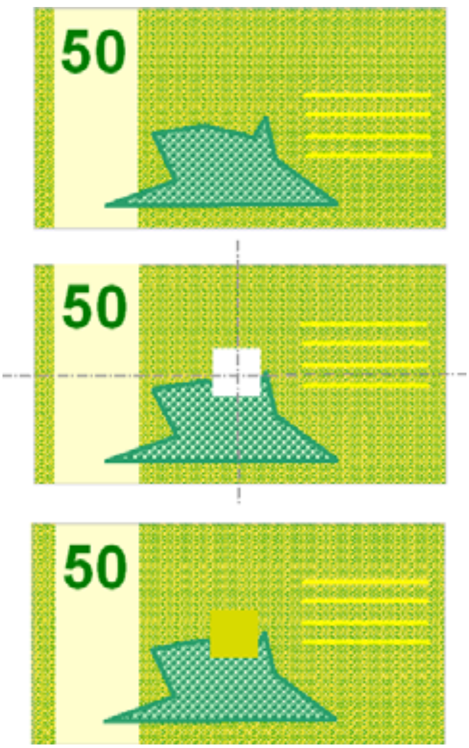
A square of 10 mm × 10 mm is digitally pasted in the centre of both the front and the back of a euro 50 banknote. The monochrome colour of the square, matches the overall colour impression of the polychrome background. The image was blurred to facilitate the matching task. The colour of this square represents the DoCol of the banknote (method 1).

background. The image was blurred to facilitate the matching task. An example of the results obtained with this technique [68] is shown in Figure A1.1.

A1.3 **Real test banknote and Pantone fan deck (DoCol method 2)**

Instead of on the basis of a blurred image, the banknote may also be judged at a distance of around 3 meter. This is a more realistic method, since the real printed banknote (additive colour creation) is used instead of a banknote reproduced by a monitor using light (subtractive colour creation). The method is described in Figure A1.2. The matching Pantone colour can be selected by a panel of 3 or 4 people. This method has been used for the research conducted in 2005 for the 'Two Year Project' [68].

Figure A1.2



a) a banknote

b) banknote with a 10 mm × 10 mm square cut out in the centre of the banknote

c) finding a colour in a Pantone fan deck (seen trough the hole) that matches the DoCol of the (polychrome) banknote

DoCol method 2, using a real banknote and a Pantone fan deck for determining the DoCol of the banknote in question.

A1.4 **Turning a polychrome banknote into a monochrome banknote (DoCol method 3)**

A third method, the 'monochrome method', was developed in 2008 [87]. It is similar to the DoCol method 1, but adds one more step by making use of a grey scale image of the banknote. This image functions as a bridge for creating monochrome banknotes, of which the colour variables can be manipulated in order to create a monochrome resemblance of the polychrome original.

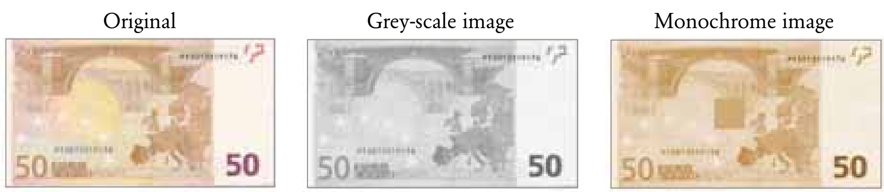
The advantage of this method is that the small 10 mm × 10 mm homogeneous test square is replaced by a monochrome banknote, with all its graphical details present. This makes it easier to select the colour variables, H, S and L, for matching the appearance of the polychrome banknote.

Once the optimal HSL-combination has been found, the next step is to determine the DoCol of the monochrome banknote, thereby following the same matching technique as used in DoCol method 1, the one with the 10 mm x 10 mm homogeneous test square pasted in the centre of the banknote. In this case this match is less difficult than in the case of the polychrome banknote, because the hue (H) is already fixed, thus leaving only S and L as remaining variables.
An example of the new technique, applied to a 50 euro monochrome banknote, is shown in Figure A.1.3.

A1.5 **Feeding the DoCol into the DoCol sampler**

Using the TNO colour-blindness simulator the DoCols of the various denominations can be visualised in the so-termed DoCol sampler, both for normal and deficient colour vision, as is shown in Figure A1.4. In this case the sampler only shows the DoCols for the current euro 50, 100 and 200 denominations, but also for a prototype for a new 50 euro banknote. The latter will be referred to as the 'Euro 50 new'. How these differences manifest themselves in deficient colour vision is shown on the right.

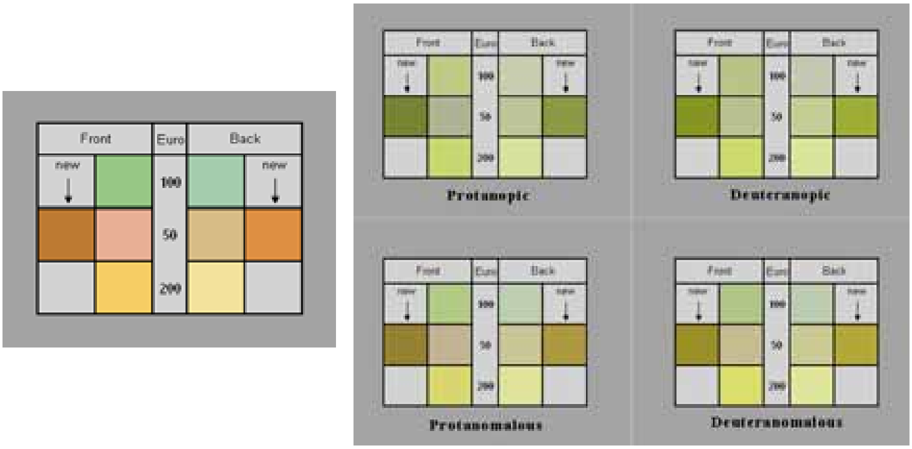
Figure A1.3



Example showing how an original banknote is transformed via a grey-scale image in to a monochrome image. The small square in the centre of the monochrome image matches the monochrome image and is the DoCol.

Figure A1.4

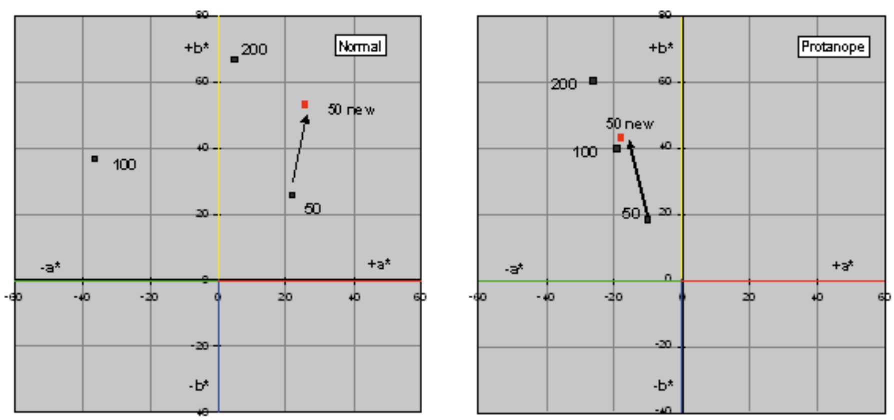
Normal vision | Colour-blind visions



Left: DoCol sampler of the current EUR 50, 100 and 200 notes and an alternative design for a new 50 euro banknote, the 'Euro 50 new'. The colour design of the latter is quite distinct from the current EUR 50 note.
Right: Colour deficiency transformations of the DoCol sampler shown on the left.

Figure A1.5

Euro 50 new for normal vision | Euro 50 new for colour-blind



Spatial representation of DoCols of the test material (front sight) in the a*,b*-chromaticity diagram.
Left: Normal colour vision. Right: deficient colour vision (protanopic).
The arrows show how the chromaticity of 'Euro 50 new' has changed relative to that of the current 50 euro banknote.

As can be seen in Figure A1.4 the colour of the ‘Euro 50 new’ is more pronounced than the current 50 euro, almost to the extent that in detonates in the design of the whole series. Whether that is desirable or not is another discussion, but it is clear that the colour-blind will have no problems in telling the different banknotes apart.

Colorimetric analysis

The DoCol sampler provides a perceptual tool for judging colour differences, but this can also be done on a quantitative (colorimetric) basis by plotting the DoCols in the CIELAB colour space. The axes of that space are L* (for the lightness), a* (for the red-green dimension) and b* (for the blue-yellow dimension). The L*a*b*colour coordinates of the DoCols are produced by the computational software of the colour editor of the TNO colour-blindness simulator. This data can also be represented by an a*b*-chromaticity diagram as shown in Figure A1.5, showing the locations of the chromaticity of the fronts of the banknotes of the DoCol sampler for both normal (left) and deficient (right) colour vision.

What can be seen is that to people with normal vision the test note has moved towards the location of the 200 euro banknote. To those suffering from protanopes, the chromaticity of the ‘Euro 50 new’ almost coincides with that of the 100 euro banknote, which is not a good development. Probably the protanopes will not confuse both notes; the lower lightness of the test note will probably prevent this (see also Figure A1.4).

Colour deficiency transformations of banknotes

Finally, the TNO Colour-blindness simulator visualises how the test note is perceived by the most extreme category of people suffering from colour-blindness. See Figure A1.6.

Figure A1.6

Protanopic (P) transformation of the test material (front). The ‘Euro 50 new’ is not shown for reasons of confidentiality. The other ones are the current euro 100, 50 and 200 banknotes.

Appendix 2

Euro coins are difficult to distinguish

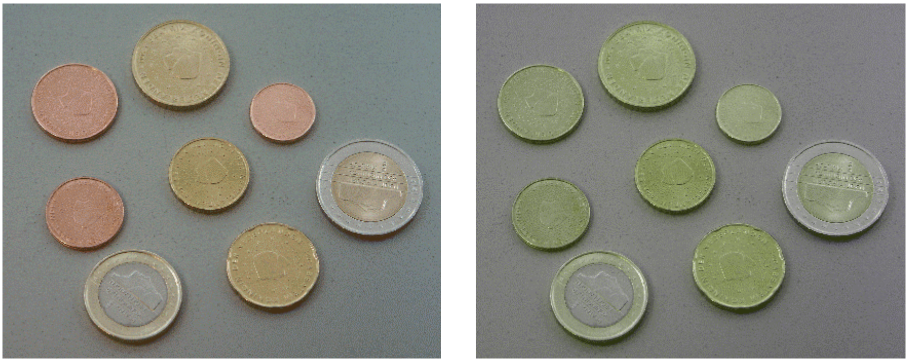
There are two reasons why the euro coins are difficult to distinguish: the sizes of the coins and their colours (Figure A2.1).
The difference between the diameters of the euro coins are fixed at 2.5 mm, except between the 5 and 10 eurocent coins (1.5 mm) and the 20 and 50 eurocent coins (2 mm). The diametrical difference between the high-value coins will only be seen as such when the differences are increasing in proportion to the diameters of those coins (see also Weber's law in Appendix 5).

Figure A2.1

Euro coins and their diameters.

Figure A2.2

Normal vision | Colour-blind



Left: normal vision euro coins.
Right: simulation of how a colour-blind person (deuteranope) sees these coins.
Pictures by Blind Color, 2002 [53].

Figure A2.3

(a)

(b)

(c)

a): First coin made from niobium, front and reverse. The coin is made and issued in Austria on the occasion of 700 Years City of Hall in Tyrol. The date of issue is 29 January 2003.
b) First full Niob (999/1000) coin series, issued by Liberia in 2004. Front side. All coins: LRD 5. Diameter 38 mm. Theme: from ancient to modern sports. Occasion: Olympic Games Athens 2004.
c) Full Niob (999/1000) coin series, issued by Rwanda in 2008. Front side. All coins: RWF 500. Diameter 38 mm. Theme: Olympic Games Beijing 2008.

Figure A2.4

Braille on coins will full fill the Braille requirements, like on this 5 dollar coin from Palau (left). On the right a USD 1 coin with Braille writing. Both coins were issued in 2009 on the occasion of the remembrance of the birth of Louis Braille in 1809.

To the colour-blind the euro coins seem even more similar than to people with normal vision, as illustrated in Figure A2.2. Similar pictures of the euro coins were published in July 2002 by the Spanish University of Extramadura [55].

Coloured coins become available
There are interesting innovations in the field of coin production, making the dream of any coin designer possible: coloured coins! Coloured coins using other production techniques are known, but they are of inferior quality: plastic ('children's money') or coated aluminium (cheap feeling, too light). Since 2003 it is possible to cover niobium (Niob) with a thin coloured layer, creating a high colour quality (Figure A2.3). This layer is applied by anodised oxidation and is about 100 micron thick. The durability of the layer is not that good and is therefore not yet used for circulation coins. So far these coins have been issued for coin collectors only.

Braille on coins
Although coins could full fill the Braille specifications, such coins are only issued for collectors. Two examples are shown in Figure A2.4.

Appendix 3

Instruction to measure the Print Contrast Ratio of the numerals on a banknote

A3.1 Print Contrast Ratio - theory

The Print Contrast Ratio PCR was first defined by Michelson in 1927 [1] and cited by the National Research Council [37]:

$$PCR = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \times 100\ \% \tag{1}$$

Where L_{max} is the luminance of the *light* region and L_{min} is the luminance (in cd/m^2) of the *dark* region.

Since banknote printers are used to working with densitometers, the Michelson formula (1) is transformed using formula (2) based on optical reflection measurements or density (D). Optical density is defined as:

$$D = -\,{}^{10}\log i/i_0 \tag{2}$$

Where i is the intensity of the reflected light beam and i_0 is the intensity of the reflected light beam of a reference material like magnesium dioxide or barium sulphate. The ratio of these two is R (of Reflection):

$$R = i/i_0 \tag{3}$$

In daily practice the reference material is replaced by a white tile. After calibration of the densitometer i/i_0 is replaced by R. When all incident light – in this case of the densitometer – is reflected by the sample, $i = i_0$ and formula (2) is transformed to:

$$D = {}^{10}\log 1/R = \log R^{-1} \text{ or } R = 10^{-D} \tag{4}$$

When none of the incident light beam is reflected $R = 0.0001$ or 10^{-4}, in daily practice the minimum detection level of a densitometer. So, for all printing products the optical density will be generally in the range of $0.005 < D < 4$.

Transformation of the Michelson formula (1) into reflection values leads to

$$PCR\ (R) = \frac{R_L - R_D}{R_L + R_D} \tag{5}$$

With R_L = reflection of the light part and R_D = reflection of the dark part.

Replacing R_L by $10^{-D\ light}$ and R_D by $10^{-D\ dark}$ in formula (5) leads to

$$PCR\ (R) = \frac{10^{-D\ light} - 10^{-D\ dark}}{10^{-D\ light} + 10^{-D\ dark}} \tag{6}$$

Taking the logarithm on both sides delivers formula (7):

$$Log\ PCR\ (R) = \frac{Log\ (10^{-D\ light} - 10^{-D\ dark})}{Log\ (10^{-D\ light} + 10^{-D\ dark})} = \frac{D_{dark} - D_{light}}{D_{dark} + D_{light}} \tag{7}$$

Replacing log PCR (R) into PCR(D) and introducing percentages leads to formula 8:

$$PCR\ (D) = \frac{D_{dark} - D_{light}}{D_{dark} + D_{light}} \times 100\ \% \tag{8}$$

A3.2 **PCS for reading OCR-B (ISO 1831, 1980)**

Next to the Print Contrast Ratio there is the Print Contrast Signal (PCS), describing the contrast between a printed image and the paper on which it is printed. This formula is used for optical character recognition, e.g. OCR-B recognition on the euro banknotes, and is described in 'Printing specifications for optical character recognition', ISO 1831 (1980). The ISO definition of the PCS formula is:

$$PCS\ _p = \frac{R_w - R_p}{R_w} \tag{9}$$

where
R_w is the maximum reflectance found within the area of interest to which the PCS of point p is referenced;
R_p is the reflectance at p.

The reflectance R_w and R_p are measured within a 0.2 mm-dia circular area.

The denominator in formula (9) differs from formula (5). The reason is that R_p is often a small figure. However, for the purpose of measuring the numerals on banknotes it is better to use formula (8), based on formula (5).

A3.3 **Print Contrast Ratio / practice**

The spot diameter of a densitometer may vary in diameter from about 3 mm to 9 mm. In case of a microdensitometer, this spot diameter can be 1.5 mm.
Figure A3.1 describes the measurement method of a denomination numeral on a banknote. At least 5 measurement points are advised (n = 5); the more the better. The measurement points should be distributed over the full height of the numeral.

The measurements done have to be averaged according to formula 10 and 11:

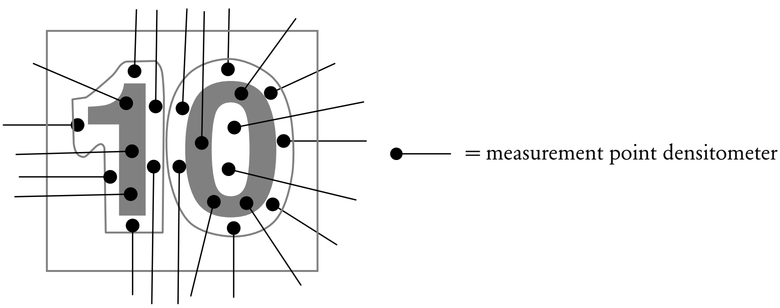
$$D_{\text{dark area}} = \sum_{i=1}^{i=n} D_{\text{dark area } i} \tag{10}$$

$$D_{\text{light area}} = \sum_{i=1}^{i=n} D_{\text{light area } i} \tag{11}$$

Entering the average values found for $D_{\text{dark area}}$ and $D_{\text{light area}}$ in formula (7) yields the required PCR (D).

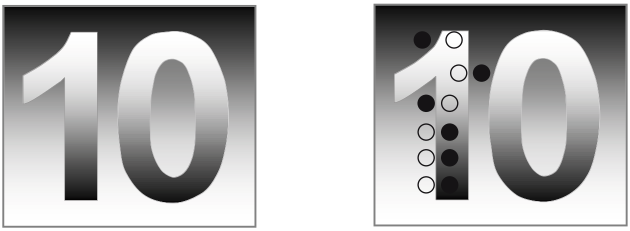
Disadvantage
The method used adds up all $D_{\text{dark area}}$ measurements and calculates the average. The same is done for $D_{\text{light area}}$. For a denomination figure as designed in Figure A3.2

Figure A3.1



Principle instruction to measure the PCR(D) of the banknote numeral and the areas in the background. For both the numeral and the background several measurements are performed. The PCR(D)-values of these areas are averaged. The contour around the numeral at least equals the width of the letter type.

Figure A3.2



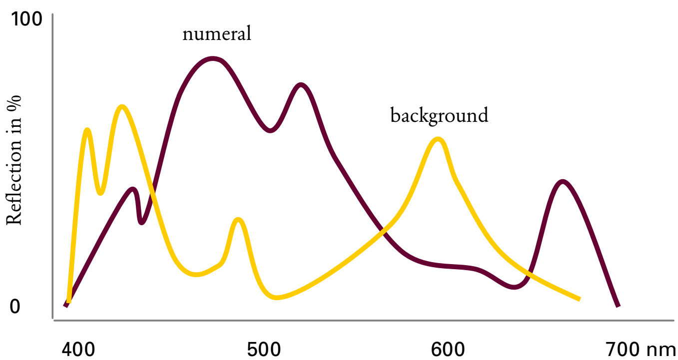
Left: the PCR(D) of this numeral will be zero.
Right: six pairs of measurement in the numeral 1.

the method used will lead to a PCR(D) = 0, since the numeral and the background both have just as many light areas as dark areas. An alternative method would be to take individual adjacent pairs of one dark and one light measurement and calculate the individual PCR(D)s. The final PCR(D average) would be the sum of all individual PCR(D)s divided by the number of measurements.

A3.4 **Spectrophotometer**

The next step would be to measure the PCR using a spectrophotometer. The full spectral curve (400 nm - 700 nm) of a printed numeral and the background could be provided in a graph. This graph will tell which parts of the numeral areas contribute most to the contrast. Again the problem of non-homogeneous areas will appear. Figure A3.3 is a simulation.

Figure A3.3



Simulation of a spectral curve of the banknote numeral and the background.

Appendix 4

Banknote dimensions: history and trends

A4.1 Introduction

Different sizes can be a helpful feature for the blind to denominate banknotes if they are large enough. Today banknote sizes prevent a reliable denominating, since over the decades the banknote sizes have become smaller and smaller.

Dimensions no (longer) a basis for a reliable value check
To date these differences, especially in note height, have become too small for the blind to be a reliable denominator. While the dimensions have diminished, the number of denominations has increased since the 1990s. As a result, denomination sizes have become too low for a reliable banknote denominating process based on dimensions. This was also concluded in 1995 by the US National Research Council (NRC): 'Although often advised by the blind themselves it seems that the variations of the dimensions of banknotes within a series are not a very reliable check on the value of the banknote.' [37].

The underlying question is: When do people experience a length difference of a banknote? In Appendix 5 it is explained that larger banknotes needs a larger length and/or height increment to permit a reliable recognition between following banknote denominations.

Emotional subject
Being in favour of different denominations, the blind probably refer to the older banknote series where size differences were larger between denominations. Abolition of size differences is clearly a highly emotive subject for the blind. Even the slightest hint of a central bank concerning the abolition of size differences will create strong feelings on the part of the blind [e.g. 8]. However, it seems – as will be explained – that the blind are better served with a large length increment instead of suboptimal length increment and a poor height increment.

The NRC, in 1995, did not offer advice on banknote dimensions. However, it did recommend thorough psychophysical studies to optimize the combination of length and height for absolute reliable value recognition on the basis of a banknote's size. It also noticed that banknote heights are more critical for machine handling than banknote lengths. The NRC found no technical literature evaluating the effectiveness of denomination differentiation by size. No such study has been conducted to date (as far as known); this appendix is a contribution.

A4.2 **Banknote dimensions**

The very first banknotes often had the same dimensions, like for example the 'Robins' first issued in the Netherlands in 1814 (all sized 195 mm × 115 mm). Around 1850 central banks issued banknotes with different note sizes. These different dimensions were not meant for the blind, but were often the consequences of different production techniques. In the Netherlands around 1860 two groups of banknotes were issued: low denominations (all sized 220 mm × 105 mm) and high (all sized 220 mm × 120 mm). The reverse of the low denominations was left unprinted, while the higher denominations included letterpress on the reverse. The intaglio gravure for the higher denominations was advised by F.G. Wagner in Berlin and the gravure was made by Mr. H. Nüsser in Düsseldorf. So both banknote types were differently originated, leading to different sizes. The printing of both was done by Joh. Enschedé [46].

Size differences decrease over the years

Over the decades banknotes have become smaller. In 1929 the sizing of the US dollar bills was standardized involving a 25 % reduction of its surface. Since that time, 1929, these dimensions were left unchanged: (length) × (height) = 156 mm × 66.3 mm (or 6.14 inches × 2.61 inches). In other countries, like e.g. in Europe, the

Table A4.1

Banknote Series	ΔL	ΔH	ΔL/ΔH	Number of denominations
DEM 1948	irregular	irregular	irregular	5
DEM 1961	10 mm	5 mm	2	7
GBP 1990	7 mm	5 mm	1.4	4
DEM 1991	8 mm	3 mm	2.6	8
EUR 2002	6 - 7 mm	5 mm, 0 mm*	1.2 - 1.4	7

Overview of the differences in banknote sizes for 4 different banknote series.
L = banknote length, H = banknote height (or width).
*) euro 100, 200 and 500 have same note height.

size differences between the denominations also became smaller. On the other hand the number of denominations increased. Table A4.1 shows some examples.

The German 1961 series is, as far as know, the first series with a consistent system for an increasing banknote size to assist the denominating process of the notes.
Contrary to Germany, the number of denominations in Great Britain decreased; the one pound note was abandoned with the introduction of the E series in 1990. Still the banknote sizes were reduced. The range of length difference was reduced from 32 mm to 21 mm, now covering 4 denominations instead of 5. The height range of these notes decreased from 29 mm to 15 mm. The criticism of the British public in 1992 was that notes have become 'too similar in size' [33].

Studies done
The very first studies to different dimensions with the purpose to denominate banknotes were done in the early 1980ths by the US Bureau of Engraving and Printing (BEP). This 1983-study was not published, but it concluded that the design feature most valuable to the visually impaired is note sizes that vary by denomination [82]. This study was not convincing enough for the NRC as mentioned in the Introduction of this Appendix. However this committee did notice the strong recommendations of the blind communities in Europe. This 'European' recommendation is most probably biased by the habits in the United Kingdom, Germany and some others using both a length and height increment. In other European countries the blind appreciated a clear length increment (by a fixed note height) like e.g. in Switzerland (1994, 11 mm), France (1992, 10 mm), Denmark (1997, 10 mm) and the Netherlands (1965, 6 mm).

Another study was prepared in 1999 by the European Blind Union (EBU) and reported, among other things, on the confusion rates when two different euro banknotes are denominated by blind people, making use of the size differences of the euro banknotes (Table A4.2).

Table A4.2

Rates of confusion	Blind respondents	Elderly blind respondents
5 euro / 10 euro	6 %	13 %
10 euro / 20 euro	9 %	11 %
20 euro / 50 euro	17 %	23 %
50 euro / 100 euro	10 %	15 %
100 euro / 200 euro	12 %	15 %

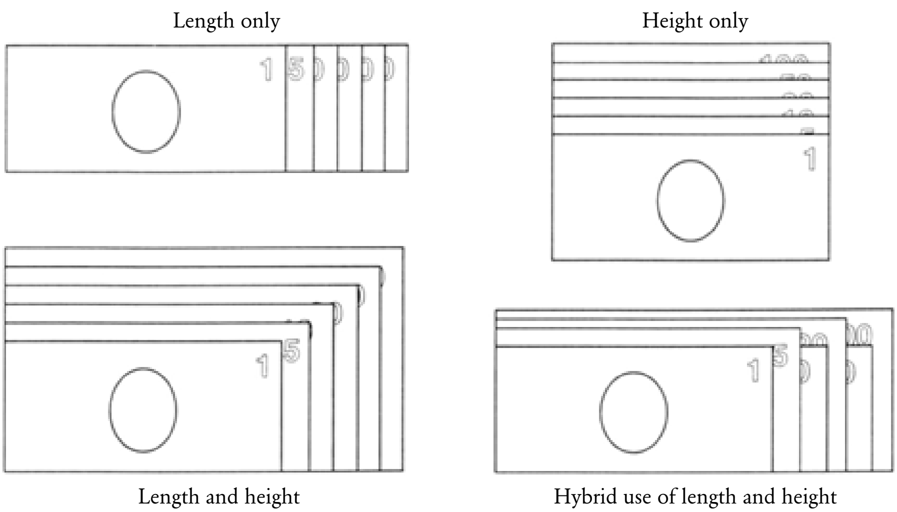
Mixing up of euro banknotes by the blind [45].

Different systems
The NRC provided four different systems for banknote dimensions (Figure A4.1). The dimensions of the euro banknotes follow the system of varying both the length and height. Today such systems become out dated; several central banks moved to a system using a standard note height and an additional length increment. Recent examples are Denmark (1997), Pakistan (2005), Azerbaijan (2005) and Mexico (2007). Other central banks also left their system using both length and height increments and printed their new denominations all the same size. Examples here are Indonesia (2004) and Venezuela (2008). The central bank of Turkey introduced in 2009 a hybrid system: a length increment for all 6 denominations of 6 mm and a height increment of 2 mm per 2 denominations.

Trend to single note height of around 70 mm
Since the introduction of the euro banknotes in 2002 no central bank introduced – as far as known – a banknote series varying both the length and the height. As said, the opposite is the case: central banks move in the direction of a single note height. The note height itself tends to an average of 70 mm (or 70 mm +/- 5 mm) [74].

Trend to length increment of 7 or 8 mm
After the mentioned period of large length increments the tendency today is to opt for a smaller length increment of 7 or 8 mm. The Swiss will reduce their increments

Figure A4.1



New banknote series can be based on variations of length and/or height increments, leading to different concepts as analysed by the NRC [37].

of 11 mm back to 7 mm in their coming 2010-series. The same increment of 7 mm is recently introduced in Azerbaijan in 2005 and in Mexico in 2008. The new 2005 Pakistan banknotes have an increment of 8 mm.

To conclude, over the years the:
- number of denominations increased,
- banknotes became smaller,
- length increment ΔL decreased,
- height increment ΔH decreased,
- ratio $\Delta L/\Delta H$ decreased,
- central banks introduce single note heights rather than irregular sizes,
- average note height tends to be around 70 mm.

A4.3 **History of the dimensions of the euro banknotes**

The euro banknotes were introduced in 2002. Before that time a wide variety of national banknotes circulated in Europe. The first attempt to harmonize all the different sizes of banknotes circulating in the European Union was made within the European Parliament. In 1986 it was proposed to introduce a single format for all banknotes to be issued in the European Union, regardless of denomination. The basic idea was that the change over to the euro banknotes would be facilitated if the EU-countries would harmonize their banknote sizes [20].

Euro banknote size based on DEM and GBP banknote series
Shortly after the Treaty of Maastricht (1992) in which the introduction of the euro was agreed, it was decided to have 7 euro denominations: 5, 10, 20, 50, 100, 200 and 500. This range was probably copied from the 1989 German banknote series, which also had 7 denominations, with similar purchasing power: DEM 10, 20, 50, 100, 200, 500 and 1,000. At that time there was also a DEM 5 banknote, but this note was replaced by a coin.

A document explaining the sizes of the euro banknotes is not yet found in the archives of the European Central Bank (ECB) or DNB. Probably there is no such document. Insiders think the history of the dimensions of the euro banknotes has been as follows. The euro banknote dimensions were set shortly after the signing of the Treaty of Maastricht, probably early 1994. Starting point were the German DEM-series and the British GBP-series of that time. The sizes of the 5 euro banknote were chosen very close to the smallest German banknote, the DEM 10. Both notes have the same height (62 mm), but the 5 euro is 2 mm shorter. The British banknote sizes were input for the length and height increments of the euro, respectively 7 mm and 5 mm (and 8 mm and 3 mm for the latest DEM-series). This is why the sizes of the highest euro denominations do not match with the highest DEM denomination. The height of the euro 500 (82 mm) is 2 mm taller than the DEM 1,000 (80 mm) and the length of the euro 500 (160 mm) is 10 mm shorter than the DEM 1,000 (170 mm).

EBU: user requirement minimum 5 mm in both length and width

The European Monetary Institute (EMI), the predecessor of the ECB, made a first proposal on the dimensions of the euro banknote series to the European Blind Union in 1994. After some minor changes the EBU agreed with the proposed dimensions and made two recommendations for the blind. With respect to the dimensions the EBU recommended: 'Different denominations must be size differentiated by a minimum of 5 mm (preferable more), in both length and width, between notes. Increasing size should signify increasing value within a series.' The second EBU recommendation concerned the incorporation of a tactile feature [38].

This minimum of 5 mm is marginal and is further limited by the banknote's size tolerances, which are often +/- 1 mm. In case of a nominal height increment of 5 mm, there is a small chance that the two subsequent notes differ no more than 3 mm in height. If the first note of two following denominations would have a length of + 1 mm and the following is cut 1 mm shorter, the difference between the two denominations would only be 3 mm. Of course this would only happen occasionally, but never the less.

Irregularities in euro banknote dimensions

The increment in length between the euro denominations has a peculiar irregularity. The intention is clearly to have all notes the same length increment of 7 mm, but for two denominations (10 and 100 euro) it is only 6 mm (see Table A5.1 in Appendix 5). But even a regular difference of e.g. 7 mm might be questioned as we will see in Appendix 5. Is the principal of a standard size difference between all denominations correct? Shouldn't the larger note have a larger increment?

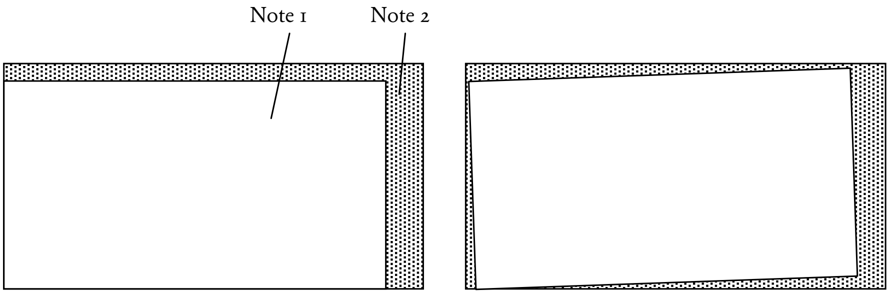
EBU research: size differences euro not sufficient

In case of irregular banknote sizes and many denominations, it may be concluded that banknotes increase only marginally in size up the denomination scale. This statement is also true for the euro banknotes as proved by research done by the EBU in 1999. Their report questions the effectiveness of the dimensions of the new euro series. Blind respondents often identified following denominations incorrectly, as is shown in Table A4.2. The EBU-research also reports that most blind are only using the length differences of the notes (see Table 7 in Chapter 4):

- comparing lengths used by 81 %,
- comparing heights used by 54 %.

This EBU report is based on 300 interviewed visually impaired people in Belgium, Germany and Spain [45].

Figure A4.2



Left: Optimum situation of comparing length and width of two successive banknotes within the euro series.
Right: Typical situation of 'skewed banknote' to compare length and width of two banknotes.

These EBU findings match with a reported finding of the NRC: When both the length and the height of four banknotes were varied – length by 7 mm and height by 5 mm – a 90 % success rate for identification could be achieved in a short learning time of about one-half hour [37].

Skew might hinder the comparison of two banknotes
An explanation for the confusion rates of Table A4.2 is the following. Comparing two successive banknote denominations by size is not as easy as it may seem. When manipulating the two notes the bottom left corners of both notes will not exactly fit. During the handling a skew might arise as is shown in Figure A4.2 (right). Comparing the length of both notes is still possible, but the note (small) height does not contribute much to a univocal decision [74].

Comparing banknote sizes: no reference
Denominating banknotes by sizes is also difficult because of a lack of any reference. If a blind person wants to compare two banknotes, e.g. a euro 10 and 20, this person may only conclude safely that one banknote is larger than the other. But how would the blind person know that it is a 10 and a 20 euro note and not a 5 and a 10, or a 20 and a 50? A Cash Test device, a tool to determine the value of banknotes, does have such a reference, the hinge of the device, and is therefore a helpful tool (Figure A4.3).

CashTest
Around 1992 the CashTest was introduced in Austria, Germany and Italy. The device uses the differences in length of the different denominations. The device has the size of a credit card and is relatively easy to use. Insert the bill into the CashTest, bend it over the edge into the measuring zone and read the raised marks at the end

Figure A4.3

CashTest, Germany, 1992 | CashTest, Italy, 1993 | Euro CashTest, The Netherlands, 2002

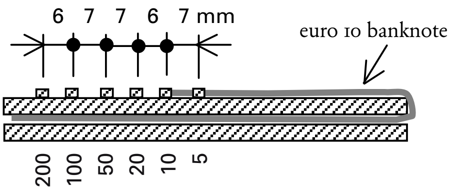
CashTest devices as introduced in three countries.

of the note with your finger. The marks are both in braille and simple symbols. The CashTest is only useable if the banknote series have differences in length.

For the new euro banknotes the Euro CashTest, improved to the CashTest, was developed by CareTec (Figure A4.3). Next to banknotes also coins can be denominated with this version. The Euro CashTest was first introduced in 2001 in the Netherlands by the 'National Forum on the Introduction of the Euro' and were provided free of charge to the Dutch organisation for the visually impaired. In 2002 this device was also adopted by the ECB and provided free of charge to the members of the EBU. According to the manufacturer it is used by 500,000 blind people in Europe (remark author: or at least distributed).

A height increment is not useful for the Euro CashTest device and might even hinder the use of the tool. The device is 55 mm wide, smaller than the euro banknote height. Therefore, the euro notes will largely stick out and will increase the risk on skewness.
There are no research reports available investigating the use of the Euro CashTest device. Earlier versions of the CashTest were not part of the 1995 study by the NRC. The use of the Euro CashTest appears to be suboptimal since the length difference between the different euro denominations is not constant (Figure A4.4). The device could be made more effective if:

Figure A4.4



Cross section of CashTest with euro 10 banknote, indicating the length increment between successive euro banknote denominations.

- Skewing would have less influence, e.g. by increasing the length increment of the euro notes to a minimum of 7 mm.
- Subsequent denominations increase with 7 mm, 8 mm and 9 mm etc.

According to Viziris the Dutch blind and partially sighted have used the Euro CashTest device during the introduction of the euro. Today the CashTest is used to denominate the euro notes at home and store the notes in the different partitions of their wallet. The CashTest itself is not kept in the wallet; using the device in shops is inconvenient and time consuming.

Introducing dummies to learn
For the introduction of the euro the ECB and the European Commission provided 28,000 kits containing dummies of the new euro banknotes. Together with a trainer disabled people, including the visually impaired, could practice in 2001 the new euro coins and banknotes [49].

Drawback: increased folding of banknotes?
Using a pocket template like the CashTest device will increase the banknote folding by the public and could be seen as a drawback of the objective of making bank notes durable. However, since the blind are a very small group (0.031 %, Table 1) additional folding because of the use of such devices will only be marginal.

A4.4 **Automatic devices**

When all denominations have the same dimensions like in Canada and the USA, a small electronic device is able to identify banknote denominations by emitting a series of 'beeps' or other signals. Such devices were first reported in 1982 by the Bank of Canada [10]. At that time this central bank was 'under a lot of pressure to make notes readily distinguishable to the visually impaired, particularly to use the favoured method, i.e. different size notes as is the case with many currencies.

But studies found that the cost of doing so would be prohibitive to the retail and banking sectors, and so the Bank developed the reader instead.' [96].

In 1989 the special device, 'The Canadian Bank Note Reader', became available for the blind. The specific machine readable features and technology used by Brytech, the producer, are trade secrets. Bank Note Readers are available free of charge through the Canadian National Institute for the Blind (CNIB). A banknote denominator is not an authentication device. The related codes in the banknotes are not secure enough to serve as an authentication system for retailers. It is for this reason that the Bank of Canada limits the distribution of the electronic Bank Note Reader to the legally registered blind.

With input from the blind community a redesigned model was introduced in 2001. This device has a more ergonomic design and is able to inform the user of the banknote denomination in three user-selected ways: voice (English or French), tone, or vibration. There is a volume control for speech and tone announcements as well as a standard headphone jack, ensuring different levels of discretion when operated in public. It recognizes all Canadian bank notes in circulation and those expected to be in circulation over the next few years.
In Canada the reader is generally well accepted by the blind community. It is made available free of charge to the legally blind via the Canadian National Institute for the Blind. Over 5,800 bank note readers have been distributed with a current steady state request of approximately 50 per month.

Figure A4.4

NoteTeller2 (USA, 2003)

Bank Note Reader (Canada, 2007)

Two banknote readers developed by Brytech.

USA and Australia

Brytech developed a similar device for the US-dollar notes, named NoteTeller2, introduced in 1992 and priced around USD 300.

For the Australian banknotes the 'Money Talker' is developed. This device has an accuracy of 99 % and takes advantage of the largely different colours and patterns on each Australian banknote. According the manufacturer the Money Talker is an effective alternative in terms of accuracy and usability [76]. The Australian blind have an option; they may also use the CashTest-Australia, since the ASD-banknotes have a single note height (65 mm) and a length increment of 7 mm.

On the internet these electronic devices are now-and-then criticised by its users for not being fast enough or not being reliable enough. Visually impaired shoppers have to rely frequently on store clerks to help them.

Unlike CAD and USD notes, euro notes have no such device readable feature. In 1995, the EBU recommended such a machine-readable code as a denomination identification tool, while stressing that such a code with an additional device should never be used as an alternative to the other distinguishing features, e.g. size and tactile pattern. The ECB did not encourage such a system, but instead supported the development of the Euro CashTest device. The Dutch blind and partially sighted will not appreciate another device, so is the opinion of Viziris. In general such devices are often experienced as rigmarole.

Appendix 5

Larger banknotes need a larger increment

In 1972 the differences between Dutch coins were brought back to a standard of 4 mm. The difference between the guilder and the 2.5 guilder was 8 mm and became the same as between two small coins (10 and 25 cent). The Dutch public got confused. In 1978 Professor Piet Vroon investigated the complaint. He found that if the larger coins would have an increment of 5 mm (instead of 4 mm) the mistakes would drop by 50 % [7, 21].
Also for banknotes it seems that the difference in size should not be a fixed value, but should increase with the size of the note. A length increment as a function of the length is logical. This function will be non linear, but is not yet known. Should it be proportional, follow the rules of the Golden Section or be logarithmic?

Weber's law
When do people experience a length difference of a banknote? For a banknote length of 156 mm it is found that a length increment of 6 mm will be noticed by 50 % of the people; a 12 mm length increment will be noticed by 75 % of the people. This research is mentioned by the US National Research Council (NRC) and is based on personal communication to two researchers on this subject: G.E. Legge and J.A. Brabyn [37].

From these experiments it can be concluded that larger lengths need larger increments if they have to be experienced as longer. This principle is founded on Weber's law:

$\Delta L / L = k.$

ΔL is the just noticeable difference and is a constant proportion of the original stimulus (L). The Weber fraction (k) is constant for any type of sensation, but varies from one type of sensation to another. Examples are lifting and holding up a weight and the intensity of a light spot. Ernst Heinrich Weber formulated this law in 1834.

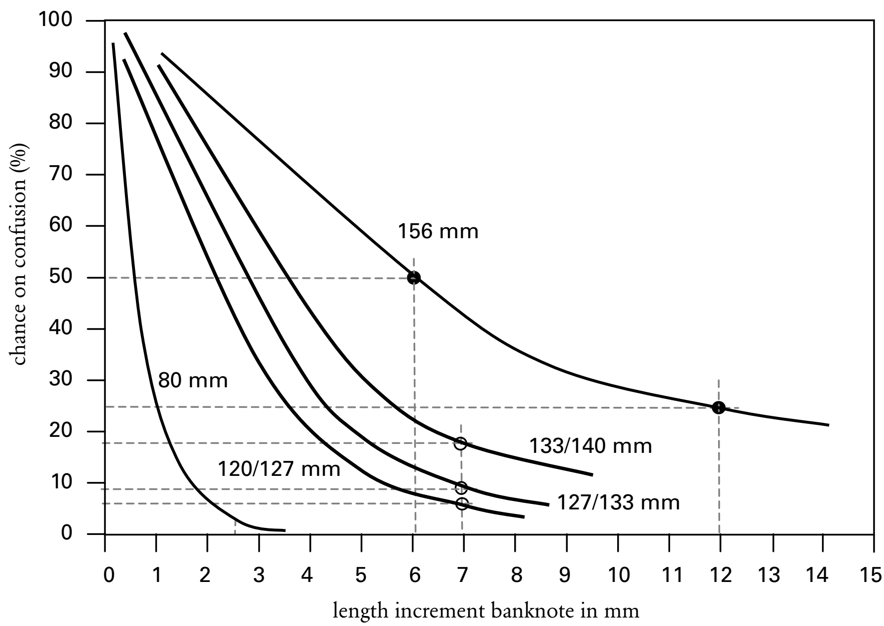
For banknotes Weber's law could be interpreted as:

$$\frac{\text{Banknote length increment}}{\text{Banknote length}} = \text{constant}$$

Inspired by the graph of Vroon, Figure A5.1 provides the expected curves for 6 different banknote lengths.

Calculation of Weber fraction for euro banknotes
The Weber fractions of the euro banknotes are calculated for their length, height and surface and are reported in Table A5.1.

Figure A5.1



Expected curves of length increments versus change on confusion for 6 different banknote lengths (80 mm, 120 mm, 127 mm, 133 mm, 140 mm and 156 mm).
Curve shapes are based on Vroon, who made this graph for NLG coins in 1978 [7].
Curve 80 mm is based on Weber fraction of 0.03 leading to 2.4 mm [37].
Curve 156 mm is based on research by G.E. Legge [37], two measurement points (●).
Curves euro banknotes are constructed using the EBU-report [45]; no measurement points (○).

Table A5.1

Euro	Length L (mm)	ΔL (mm)	ΔL/L (mm)	Height H (mm)	ΔH (mm)	ΔH/H	Surface S (mm²)	ΔS (mm²)	ΔS/S
5	120	7	0.058	62	5	0.081	7.440	1.069	0.143
10	127	6	0.047	67	5	0.075	8.509	1.067	0.125
20	133	7	0.053	72	5	0.069	9.576	1.204	0.126
50	140	7	0.050	77	5	0.065	10.780	1.274	0.118
100	147	6	0.041	82	–	–	12.054	492	0.041
200	153	7	0.046	82	–	–	12.546	495	0.039
500	160	–	–	82	–	–	13.120	–	–

Calculation of Weber fraction of existing euro banknotes (series 2002) for length, height and surface.

From this table it can be deducted:
- Not any of the three variables (length, width and surface) of the euro notes are used consistently through out the series.
- The Weber fraction is not constant for any of the three variables.
- The largest Weber fraction is delivered by the difference between the surfaces of the 5 and 10 euro (0.143). These two notes are best discriminated from each other by their surface.
- To create a constant Weber fraction (of 0.058) the length increment should start at 7 mm from the 5 to the 10 euro and should increase to e.g. 7.4 mm for the euro 10 to euro 20 (0.058×127 mm = 7.37 mm).
- To create a constant Weber fraction (of 0.081) the height increment should start at 5 mm from the 5 to the 10 euro and e.g. increase to 5.4 mm for the euro 10 to euro 20 (0.081×67 mm = 5.43 mm).

A Weber fraction of 0.03 was the NRC committee's best available estimate of a lower bound of appropriate length differences for banknotes. It seems that this lower bound should be set much higher, at least at 0.06.

Appendix 6

Blind marks: history and trends

A6.1 **Introduction**

In 1995 the US National Research Committee (NRC) was unable to identify any tactile-only feature that can be implemented without any further research being required [37]. The opinion of the EBU in that same year is that tactile features may be useful if they are resilient enough to last for the circulation lifetime of the note [38]. There is a hesitation to rely on tactile patterns, because the first single marks were not successful.

Blind not happy with single marks
Research conducted on the use of single marks by the blind show that the blind are (often) dissatisfied with such a feature for the following reasons [24, 26, 29]:
- The relief of the single mark is not high enough.
- The effectiveness of the relief of the single mark is reasonable on new notes, but poor on circulated notes; the relief is not durable.
- The single marks are too small.
- The single marks are often hard to find (often on just one corner or close to the edge of the note).
- (Poor working) single blind marks are found to be patronizing and or stigmatizing.
- The blind have to become familiar with the marks.

From opinion polls done in the Netherlands it is learned that many people recall spontaneously the 'blind marks' as one of the features of a banknote. This is unwanted attention of the general public for the blind marks, since it is first of all a denomination feature and not a full security feature. Since the public's ability to recall banknote security features is limited to around 3, it is desired that the public will recall some public security features. In the case of 'blind mark' it would be preferred if they would recall 'tactile relief'. The public's attention for 'blind marks' in banknotes is waning in the preferred direction. Public awareness of 'blind marks' in the Netherlands dropped from 49 % in 1983 to around 10 % in 2007 [28, 90].

A6.2 **Why don't they use Braille?**

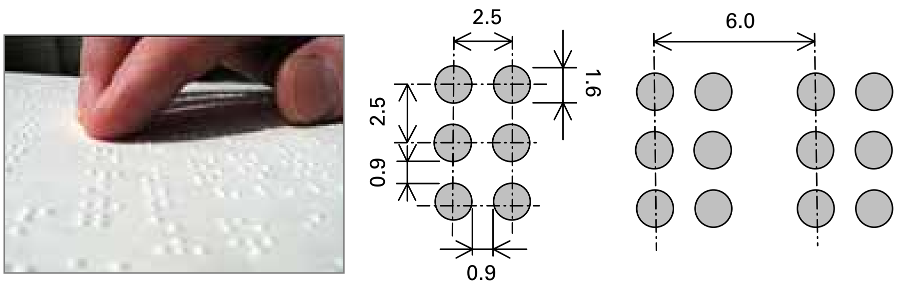
Why don't they use Braille? This is often the first remark people give concerning banknote features for the blind. In 1981 it was proposed to amend the Bank of Canada Act to require that each note be provided 'with denomination numerals in regular print and in Braille'. The answer of the Bank of Canada was that the achievable relief in banknotes would only be about 0.03 mm (30 µm), much less than the 0.45 to 0.5 mm needed for Braille [10]. Others, like the Bank of England, argued further that only very few blind are able to read Braille [8]. And this is also true in the Netherlands were today Braille readers, e.g. readers of books, are less than 1 % of the population of the Dutch blind (1.500 to 2.000 people). It is expected that this number will decline in the future as speak synthesisers are improved. 'It is true that Braille receives excessive attention from the authorities' was said by the manager of Viziris, the Dutch organisation for the visually impaired in 2008 [92]. There is a larger group of Braille readers using Braille for short texts on e.g. medicines, spices, CD-boxes etceteras. Still the majority of the blind are not using Braille. However, Braille is a powerful brand and several central banks refer to their blind mark as the 'Braille feature', like e.g. the central bank of Malaysia in case of the new MYR 50 banknote. In Singapore these marks are known as 'Braille codes'.

Braille on stamps
In 2009 Louis Braille was born 100 years ago in France. For this occasion he is remembered on Belgium and Dutch post stamps. These stamps have Braille like printing. The first stamp using Braille printing was issued in Brazil in 1974. In 2006 Ireland issued a stamp with Braille like printing. A question remains if the relief on all stamps meet the minimum required height of 0.23 mm. Over the years many post stamps were issued with Braille signs, although not in relief (e.g Netherlands in 1974 and 1985).

Inventor Louis Braille
Louis Braille became blind by accident when he was 3 years old. In 1824 at the age of 15 he invented the Braille script. From the six dots that make up the basic grid, 64 different signs can be created, enough for all letters and figures, punctuation marks, mathematical symbols and even music notes. One sign has no dots, the spacing. See Figure A6.1.

The Braille system established itself internationally, and is now in use in all languages. There are several standardised specifications for Braille (1920, 1957). In daily practice these specifications can differ from country to country. Today the Marburg

Figure A6.1



Left: reading Braille.
Middle: basic dimensions of Braille as used for medical packaging.
Right: spacing between two Braille characters is 6 mm. Line spacing = 10 mm. Hyphenation = 12 mm.

Medium is the most commonly used and advised by the European Commission for use on pharmaceutical packaging and labels. The European Carton Markers Association has also followed this specification with their ECMA Braille Standard. This is the specification given in Figure A6.1 [69].

Braille: dot height
The Braille dots should have the shape of a cone. The recommendations of the height of the cone may vary from 0.23 mm (printed Braille) to 0.38 mm (Standardisation 1957) and even up to 0.5 mm (American Braille Technical Specifications set by the National Library for the Blind and Physically Handicapped Materials Development Centre).
For carton the cone height is not specified. The embossing height should 'be determined visually, since the deformed carton is likely to recover slightly over time. The upper tolerance level is reached when the surface of the folding carton starts to burst.' For the European Union new legislation is being prepared, proposing a height of 0.2 mm and not below 0.12 mm.

Bankote printing not high enough for Braille
The maximum printing relief in intaglio – based on chemical etching of the printing plate – is only up to 0.06 mm (60 µm), far below the lowest Braille specifications. The new digital intaglio origination techniques make it possible to print cone heights up to 0.1 mm (100 µm), still not enough for Braille (see Appendix 10). This is the reason why Braille could never be properly introduced on banknotes if only intaglio would be used. The Braille-like dots on the recent Canadian banknotes – see section A6.6 Tactile feature in Canadian banknotes – have a minimum dot-height of 0.11 mm (110 µm) [79].

Inform the blind
To be effective, the blind should be informed about the tactile symbols, as was found by DNB in 1989 [24, 26, 29]. Learning processes are required for a proper use of features for the visually impaired is also the advice of the NRC [37]. In line with these advises, the Central Bank of Bahrain issued in 2008 a special brochure in Braille, which provides information about the new banknotes. The brochure has been produced in conjunction with the Saudi-Bahraini Institute for the Blind.

A6.3 **History of blind marks**

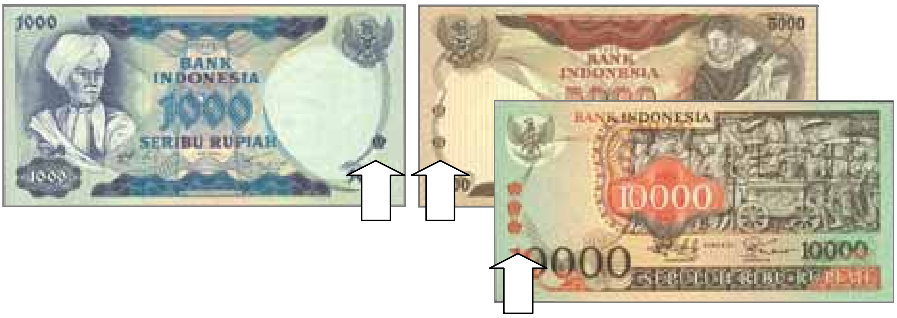
In 1971 DNB started to issue banknotes with dedicated 'marks for the blind' (Figure A6.2). The marks were suggested in 1968 by a visually impaired employee of Joh. Enschedé, Mr. Eugene A.M. Loeff. Since it is more difficult to remove a dot than to add one, the lowest denomination received three dots. No blind mark was given to the NLG 1,000/Spinoza, which was often misunderstood. Looking back it would have been better to include also a tactile mark on this note.
These blind marks were several times imitated in counterfeits using the head of a nail.

The first to follow the Dutch example was the Central Bank of Indonesia. In 1975 a series of Rupiah banknotes was issued with a similar approach as the guilder notes

Figure A6.2

First banknote series with tactile marks for the blind. First note was the NLG 10, issued on 4 January 1971. 'Dots for the blind' were positioned in the left bottom corner. Three dots for the 10, two for the 25 and one for the 100. Dot diameter 5 mm, distance in between 4 mm. The NLG 1,000 has no tactile mark.

Figure A6.3



Introduction of marks for the blind on Indonesian banknotes in 1975. Solid pentagons with a 3.5 mm side. Heart to heart distance at IDR 5.000 is 8 mm and 12 mm on IDR 10,000.

had. Instead of a round dot a pentagon shaped element was introduced (see Figure A6.3).
In Europe the Swiss were the first to follow the Dutch example. The first Swiss franc note with a 'code for the blind' was issued in 1976 (Figure A6.4). These tactile symbols were smaller than the Dutch and were more effective. It was learned that not so much the size of the blind mark is dominant, but the steepness of the slope of the relief.

In the years that followed several central banks came with their own marks for the blind, like Belgium, Israel and Iceland. By 1995 around 10 % of the issuing authorities used marks for the blind on their banknotes [37]. These marks were certainly not uniform; each central bank developed its own variant. Table A6.1 provides an overview of the first adopters.

Figure A6.4

Introduction of 'code for the blind' on the Swiss banknotes in 1976. The system is using small dots for the low denominations and short straight lines for the higher denominations [6]. The dot diameter is 2.3 mm and their heart-to-heart spacing is 5 mm. The thickness of the lines is 0.3 mm and their heart-to-heart spacing is 4 mm. Design: Ernst and Ursula Hiestand.

Table A6.1

Year	Central Bank	Blind mark type	Size	Heart to heart
1971	Netherlands	Dots ('nail' type)	Ø 5 mm	9 mm
1975	Indonesia	Pentagons (solid)	Side 3.5 mm	8 and 12 mm
1976	Switzerland	Dots (solid)	Ø 2.25 mm	5 mm
		Vertical stripes	4 mm x 0.3 mm	4 mm
1978	Belgium	Dots (solid)	Ø 2 mm	7.5 mm
		Open circles	Ø 3.5 mm	24 mm
1978	Israel	Dots ('nail' type) and other types	Ø 5 mm	10 mm
1981	Iceland	Dots (solid) and one stripe	Ø 1.5 mm	5 mm

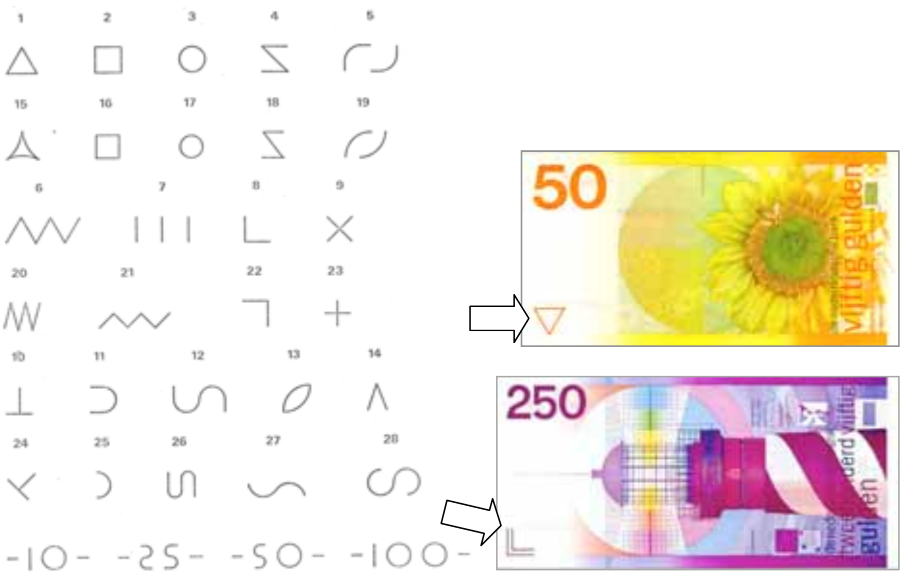
Historical overview of the introduction of marks for the blind (as far as known to the author; partly based on research done by Mr. Robert Tausk in 1984 [16].

Some issuing authorities introduced just one banknote denomination with a mark for the blind. This was the case in France in 1978 when the FFR 100 was issued (solid dots Ø 2 mm, h.t.h. 5.5 mm) and in Finland when in 1980 the FIM 10 was introduced (cluster of 4 solid dots, Ø 3 mm h.t.h. vertical 5 mm, horizontal 8 mm).
Luxemburg followed the code of the BEF 100 on their 100 Franc note in 1980. Guatemala introduced in 1980 combinations of lines, dots and Maya-symbols on their series. A denomination codification along the short side of the banknote, being an integral part of the note design was first introduced by Sri Lanka in 1982. The National Bank of South Korea followed in 1983 the 'nail' type NLG-marks. In 1994 the National Bank of Poland introduced large and obvious marks for the blind (Figure A6.5).

Figure A6.5

Polish banknote series with large and obvious marks for the blind (1994).

Figure A6.6



Left: different marks were designed (1980) to select a new tactile mark on the NLG 50/Sunflower issued in 1982. Tested on 5 persons (blind or blind folded) delivered the triangle (design 1) [28].
In 1984 similar tests were done to further improve the tactile mark for the new NLG 250/Lighthouse. The double lines were favoured by 5 Dutch blind over single lines [17, 28].

Triangle shape

In 1982, the NLG 50 banknote, a completely new denomination, was introduced and a new mark for the blind was needed. On DNB's first written specification for a blind mark [9] several possibilities were designed and printed in intaglio (see Figure A6.6). These marks were tested in purposefully designed experiments amongst others by a blind female employee, the telephonist, of the printing works. As a result, an open triangle with a basis of 10 mm was chosen. The line width was 0.5 mm and height of the intaglio ink about 0.06 mm. The triangle was also selected because it gave a good distinction from the 'old nail type blind mark', so that people would know this is the new 50 guilder note [11].

Spacing of tactile lines

The procedure used for the 50 was repeated for the NLG 250 banknote, another new denomination, issued in 1986. This triggered also the idea of the spacing between two lines [12]. Again central bank, designer and printing works developed a set of possible marks.

To test the marks DNB invited the blind for the first time at its head office in Amsterdam. The year was 1985. From 5 slightly different L-shaped symbols a representative group of 5 blind people from the Dutch Blind Association chose a double

L-shaped symbol with a spacing of 1.5 mm. The blind were accompanied by their dogs, a memorable experience!
It was learned that the tactility was improved by printing a double line instead of a single line, although the blind were not really satisfied. To the press they made the following statement: 'For the new banknote four options were offered by the central bank. Finally we chose the least worst. If they could make the relief a bit stronger, many blind would be helped.' [19].

A6.4 **Evaluation effectiveness of marks for the blind in NL**

In 1986 the Dutch central bank wanted to know if the marks on their banknotes were really useful. For this reason a research was done to measure the effectiveness of the marks used, together with the TNO Institute for Perceptional Research. Assistance was given by the organization representing the blind in the Netherlands. After preparation of test material, the research was done in 1988 and is described by Dr. Lex Wertheim of TNO [24] and Dr. Peter Koeze [29]. Dr. Wertheim made – on special request of DNB – also a public article on the research [26], which was quoted several times in the Dutch press [e.g. 27].

Large scale experiment 1988 *by DNB*
Never had a scientific large-scale experiment with blind people been carried out before. A total of 40 blind people were selected to participate in the experiment. All selected blind persons could read Braille. The idea behind this criterion was that if people familiar with Braille could not use the tactile marks, others would most certainly experience difficulties with the tactile marks.
The 40 blind people were further selected so that three subgroups could be created:
- people born blind,
- people became blind before their fourth year,
- people became blind later in life.

In total 30 different types of test notes, including the real notes in circulation, were involved in the experiment. Also new and circulated notes were tested.

In short the results were the following:
- The main conclusion is that the marks for the blind were not very helpful. Knowledge about the tactile marks was poor; slightly more than half the marks (54 %) were correctly described at the start of the experiment.
- 42 % declared that they never make use of the marks in practical situations. The reason for this is social pressure from the situation in shops. The blind are hesitant to show distrustfulness towards shopkeepers and do not want to keep other customers waiting in the queue behind them.

- A second reason is that the marks were barely tangible on used notes; the folds and crumples in the paper in the vicinity of the marks leave behind a relief which is of the same magnitude as the relief in the marks (signal-to-noise ratio of the tactile marks deteriorates with the aging of the notes).
- A dramatic increase in the identification score was achieved after the participants were trained to recognize the marks. Training of the blind increased the score of 54 % to almost 100 %.
- Other tactile features were of no use.
- Test notes with marks were significantly better identified than notes without marks.
- The dimensions of the note played a minor role (only length increment was tested).
- No difference was found between early blind and late blind participants.

At the end of the main experiment with each of the 40 participants a list of questions was read to them. The same list of questions was also put to another 60 blind people.
The blind were also invited to give suggestions for improvement. Remarks made were:
- Marks should be on every corner of the note.
- Introduce edge modification.
- The Dutch blind said that they select banknotes at home and store different banknotes in different compartments of their wallet.

Figure A6.7

First banknotes with tactile mark for the blind in paper were the Japanese Yen-notes, issued in 1984. The centre dark dot is + 10 μm above the plain paper and the light parts are - 50 μm below the plain paper. Codification: 1,000 = one mark, 5,000 = two marks vertically and 10.000 = two marks horizontally.

A6.5 **Tactile marks in paper**

In 1984 the Bank of Japan introduced tactile marks for the blind into the paper. The basic mark was a circle with an inner dot (Figure A6.7). The marks were systematically used over the three notes in circulation. The Bank of Japan abandoned this approach with their new series in 2002 and introduced printed marks for the blind. Probably because holes or depressions are much harder to 'read' than positive displacements like bumps or points [37].

A6.6 **Tactile feature in Canadian banknotes**

In 2001 the Central Bank of Canada issued the first note with the so called 'Tactile Feature for the Blind' or TFB. This feature is developed in consultation with blind and visually impaired Canadians. The tactile feature is located in the upper right corner on the face of *Canadian Journey* series notes. The symbols used are no Braille, since they have different specifications. But just as the Braille-script it consists of a series of symbols formed by groupings of six raised dots separated by a smooth surface. Each symbol is composed of two columns of three raised dots. These dots are embossed and back-coated in additional production run to prevent the dots from flattening out. The number and position of these symbols vary according to the denomination. Minimum height at production: 0.11 mm (110 μm) [79]. See Figure A6.8.

Figure A6.8

Left: codification principle. The CAD 5 note has one symbol, the CAD 10 note has two symbols separated by a smooth surface etceteras. Like the 10 note, the new CAD100 bank note has two symbols, but the smooth surface or space between them is wider.
Right: detail of Tactile Feature at the top right of the CAD 10 note (2 symbols comprised of six dots each).

Assessment
The feasibility of the TFB was assessed in a study by Lederman in order of the Bank of Canada [56]. The assessment was done in two stages reducing 8 different designs to a selection of 4.
The first selection was done by 20 blindfolded, sighted university students. Across the 8 design series, the proportion of correct responses never fell below 0.97; the mean response time per banknote ranged from 11.4 to 13.1 s.
In a second experiment, 27 functionally blind participants denominated 4 of the previous 8 candidate sets of banknotes. The proportion of correct responses never fell below 0.92; the corresponding mean response time per banknote ranged from 11.7 to 13.0 s.
Denominating a banknote's value on the basis of the tactile feature on the latest CAD notes takes on average 12.6 s, which is quite long. It should be noted that the tests carried out on the feature were done with limited training and the notes were given to the test participants in random fashion. With practice the speed definitely increases. The overall assessment of the tactile feature was quite positive, the main area for improvement being in its durability.

A6.7 **Daily practice in 2009**

Today several central banks base their tactile denomination features still on blind marks. Often they use the system as exemplified in Table A6.2 or a variation of it. This system based on dots and small stripes is in fact the system used for the Swiss banknotes in 1975. Some recent examples are provided in Figure A6.9.

Table A6.2

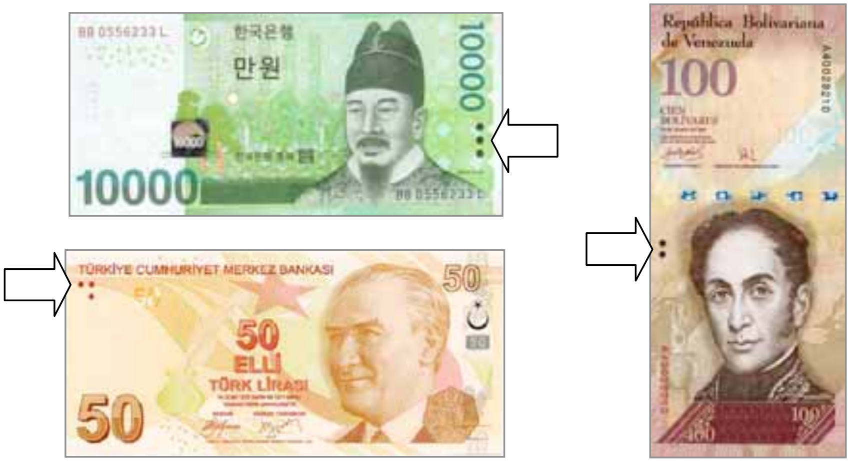
	Denomination					
	1	2	3	4	5	6
Blind mark	•	••	•••	▌	▌▌	▌▌▌

Popular codification system for single blind marks.

Figure A6.9

South Korea, 2007

Venezuela, 2007



Turkey, 2009

Three recent banknotes with single marks for the blind using dots.

Appendix 7

Tactile structure with codification

A7.1 Introduction

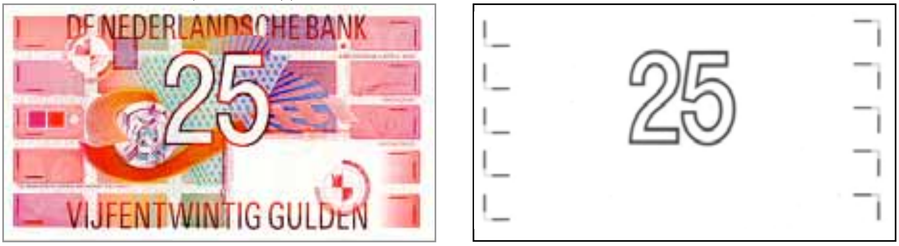
The single blind marks were not a satisfying solution to discriminate banknote denominations by touch, as is explained in Appendix 6. The single marks evaluated to a tactile structure with codification, the reason for creation of this Appendix 7.
One of the banknote's public security features is its tactility by relief print. Often this tactility is not exploited to the maximum. Tactile areas usually come – as in the case of the euro – with the main image and some texts. Large dedicated tactile areas are not part of the design. If such dedicated tactile areas would be introduced, a denomination code could be included. This code could be learned by the blind and be useful in denominating the note. The focus of the general public on single blind marks would diminish.
In 1992, such tactile areas were first introduced on the NLG 100/Little Owl [30, 36, 81]. All following designs had different tactile areas. Although no quantitative research on these tactile areas was ever conducted, the Dutch blind praised this note's tactility.
The euro banknotes followed this approach with the euro 200 and 500. Listening to the need of the blind, it is only logical to introduce such tactile areas to the lower denominations as well.

A7.2 From single mark to multiple marks

In 1986 a double L-shaped blind mark was introduced on the NLG 250 (see Figure A6.6). For the next banknote, the new 25 guilder DNB proposed again a double line for the new blind mark. The selected designer for the new Dutch banknote series, Jaap Drupsteen, was not convinced. He did not like the aesthetics of such marks. Instead he proposed to use 10 single L-shaped marks along both short edges of the new NLG 25 guilder banknote (Figure A7.1). The argument to position the blind marks on every corner of the note was in line with the evaluation of the large scale

Figure A7.1

NLG 25/Robin, 1990 | Ten tactile marks



Bridge between single blind marks and a tactile structure: the NLG 25/Robin, issued on 27 March 1990. 5 L-shape tactile marks on each side of the note. Line width: 0.5 mm. Line distance: 13.5 mm. Relief: 60 µm. X-height numeral: 30 mm.

experiment in 1988 (see Appendix 6). Also the large numeral 25, printed in outline with maximal relief, could be detected by the blind.

Integration of the marks was realized by using the grid of 25 units for the location of the marks. This way the marks were no longer the characteristic elements they had been as in the old notes. DNB accepted the arguments and proposals of Jaap Drupsteen, since the blind found the double L-shaped mark only a little improvement to a single line [28]. With this banknote DNB was first with tactile codification in texture rather than single marks.

A7.3 **From multiple marks to texture**

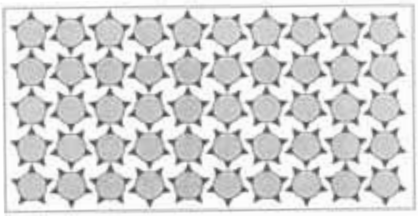
Before the next notes could be designed, DNB asked Jaap Drupsteen to make a plan for the complete series. The plan should be based much more on tactile structures, rather than using single symbols or marks. Such a pattern should be based on a basic design element, the generic tactile element, which can be a dot, a line or any other abstract element. Drupsteen's codification plan [30] was accepted by DNB, Figure A7.2 shows some examples. In 1989 the development of the new NLG 100 banknote started. The proposed dots for this denomination were developed during the design process, as is shown in Figure A7.3.

Tactile pattern printed in transparent intaglio ink

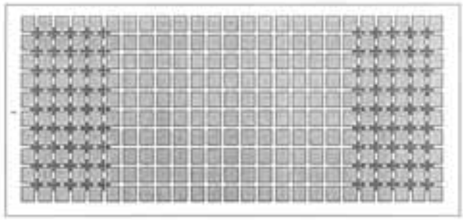
Since the relief is the most important parameter for a mark for the blind, the ink itself could be colourless. Originally intended as an anti-colour copier feature, the texture was printed in a colourless, transparent intaglio ink. Such colourless ink has two advantages: it cannot be copied and the design would not be disturbed by the dot pattern used over a large area. The colourless ink gives therefore also a greater freedom to the graphic designer.

Figure A7.2

Tactile structure NLG 50



Tactile structure NLG 25 0



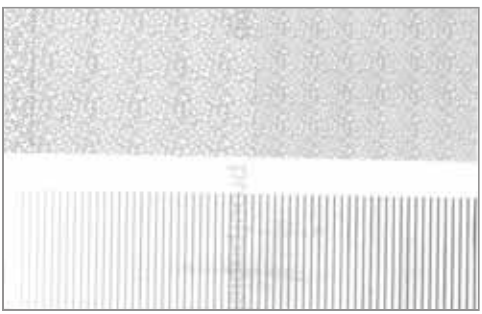
Part of design study by Jaap Drupsteen for the development of a tactile texture plan for the NLG-series (1990).

Tactile structure
In a tactile structure the generic tactile elements like i.e. chevrons, dots and wavy lines, are with many and are densely spaced. These tactile elements will cover an area of the banknote with a texture rather than being a solitary figure or symbol. A texture provokes a more acute stimulus of the tactile sense than a solitary symbol. The distinctive raised feel is also used by the general public, since intaglio relief is one of the public security features. In this new NLG 100 note, value recognition and security control are for the first time effectively integrated in one feature (Figure A7.4).

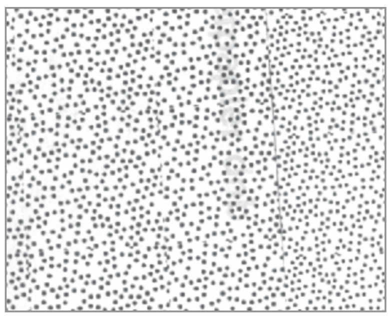
A texture consisting of relatively small dots or thin lines for that matter is much more readily perceptible by touch [36]. Two more NLG-notes were issued before the introduction of the euro banknotes. The NLG 1,000 received parallel waving lines, again printed in a transparent intaglio ink. Apart from a good intaglio relief,

Figure A7.3

Test print dots and lines



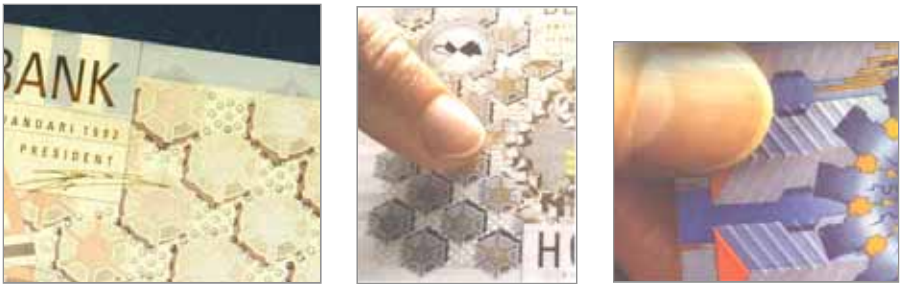
Enlarged part of dot-area



Parts of study to print highly tactile elements (lines, dots) in several dimensions. The study also included the use of transparent intaglio inks. DNB/Joh. Enschedé (around 1990).

Figure A7.4

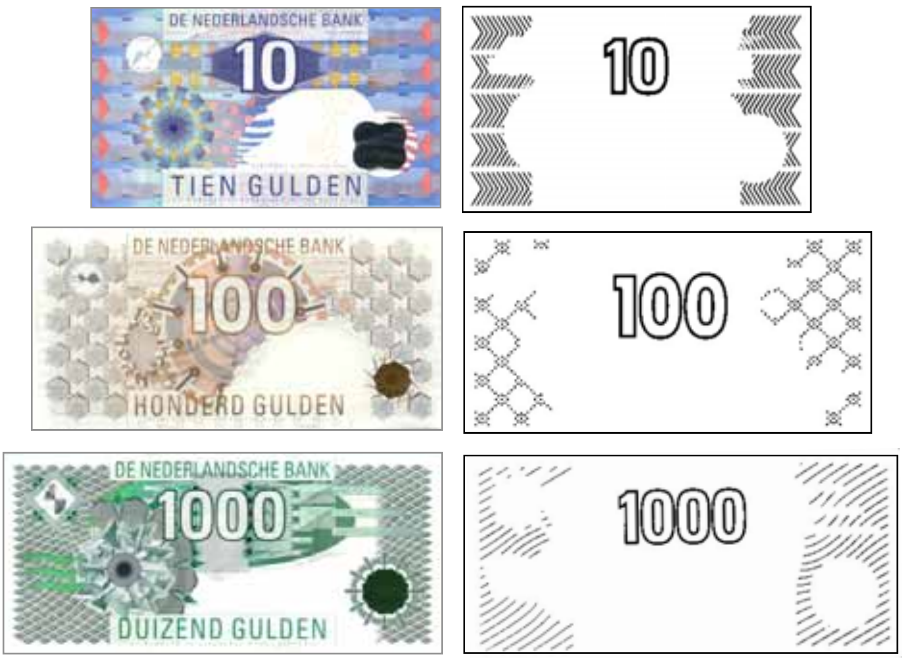
Dots in NLG 100 Chevrons in NLG 10



Banknotes with tactile structures. NLG 100/Little Owl (1993) is the first note with a tactile structure using dots. In 1997 the NLG 10/Kingfisher was issued with tactile structure using chevrons. Both structures are printed in transparent intaglio.

Figure A7.5

Banknote Tactile areas



Overview of the tactile areas in the NLG-banknotes based on a preset master plan by Jaap Drupsteen.
Specifications: NLG 10/Kingfisher. Generic element: chevrons. Issued: 1 September 1997.
NLG 100/Little Owl. Generic element: dot. Dot diameter: 1 mm. Dot distance: variable, around 0.6 mm. Dot height: 70 micron. Issued: 7 September 1993.
NLG 1,000/Lapwing. Generic element: slightly curved line. Line width 0.4 mm, line distance variable 3-3.5 mm. Relief: 60 µm. X-height numeral: 19 mm. Issued 2 April 1996.

the blind commented that they could also feel the smooth foil area! In 1997 the new NLG 10 was issued using chevrons, also in transparent ink (Figure A7.5).
The blind were interviewed once more by DNB before this note would be issued. They were content with this last series of NLG-notes. In general they were in favour of good tactility marks over length increments (of 6 mm).

A7.4 **European banknotes**

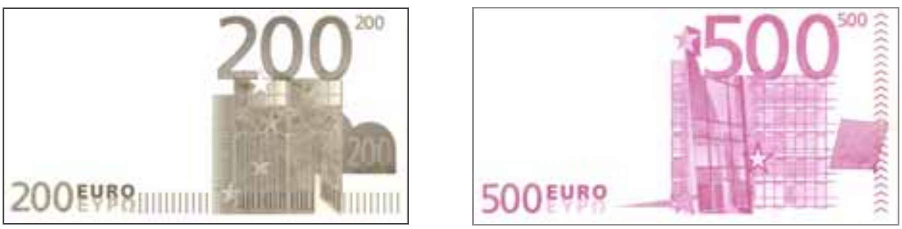
For the euro banknotes it was decided to have tactile structures on the new euro banknotes following the EBU recommendations, which were based on the experiences with tactile structures on the NLG-notes [38]. Since the EBU was first of all in favour of different sizes, the tactile structures were only proposed for notes similar in size: the EUR 100, 200 and 500. To be able to discriminate these three denominations it was decided to have a tactile pattern only on the 200 and 500. The same reason was used for the euro 100 as was used in the early 1970ths to have no blind mark on the NLG 1,000: if there is no tactile structure it is the 100 euro.

In 1997 the ECB (at that time European Monetary Institute: EMI) prepared two test notes with a tactile texture as shown in Figure A7.6. After testing by the EBU the chevrons were replaced by straight lines (Figure A7.7) [40, 41].

No tactile codification on low denominations
The Dutch blind reported they missed the tactile patterns on the lower denominations of the euro banknotes and questioned the tactile marks on the 200 and 500. 'We do not have those notes in our wallets!' is their statement.
The Netherlands Federation of the Blind and Partially Sighted (Viziris) asked DNB in 2005 for better tactile features on the euro banknotes and a greater difference in length (e.g. 8 mm) between the notes returned in daily payments [50, 74].

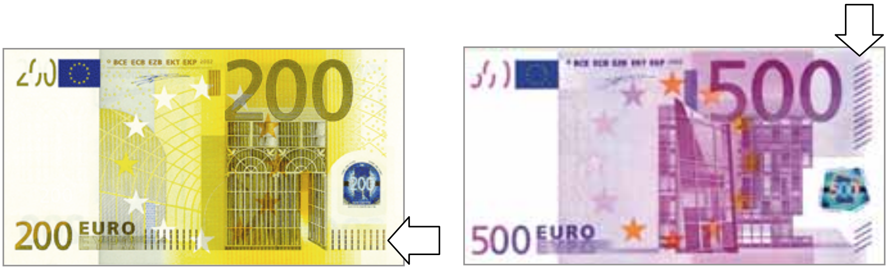
Figure A7.6

Tactile lines along long side | Tactile chevrons



Test notes for the euro series, prepared in 1997 with different tactile structures on the euro 200 and 500. The v-shaped marks on the 500 were later changed to straight lines on request of the EBU.

Figure A7.7



The euro 200 and 500 with tactile structure for value recognition and security. Chevrons on euro 500 were changed into lines on requrest of the EBU. Both notes are issued on 1 January 2002.

A7.5 **Dot proposals by DNB**

In line with the good tactility of the NLG 100/Little Owl, DNB proposed in 2001 dot structures for future euro banknotes. The cloud of dots is in invitation to touch, to follow with your finger. Figure A7.8 also provides some further design suggestions.

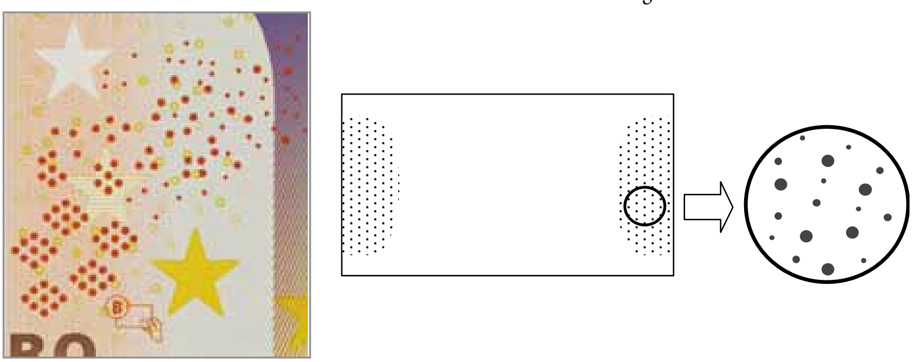
A7.6 **Design principles generic tactile element**

The central bank and designer should fill each tactile structure on the individual banknotes with a clearly discriminating pattern. It could also be a symbol like a star or a leaf. The generic tactile element should not be too complex, no guilloches.

Figure A7.8.

Invitation to touch

Tactile codification using different dot sizes



Tactile structure inviting to touch: a mathematical array of dots fanning out in a cloud of dots of different diameters. Structure developed for new euro series by DNB in co-operation with Ms. Inge Madlé of Joh. Enschedé (2001).

Dinse found that a group of generic elements should not have an outline [99]. Other findings are that concentric/parallel patterns increase the tactile sensation. And people tend to get confused with multi-side polygons (more than 4 sides).

Recently some central banks reported about their search for the best generic tactile structure (see the next section A7.6 Discrepancy in the outcome of studies), but non of these studied a set of denominations, either the pay-back notes or the complete series. All focussed on the best tactile element instead of a research to a system for the complete series.

A7.7 **Discrepancy in outcome of studies**

Some research is done to the tactile effect of dots versus other designs. However the findings contradict each other. Two researches, one by Dinse [67, 99] and the other by the ECB, conclude that line patterns are better recognised over dot patterns. The ECB investigators asked in 2007 which of 7 different patterns offered would be the best to the blind respondents. The outcome was lines with a wide spacing [94]. A third, joint study of the Bank of Canada and the Bank of England reported in 2007 the opposite: dots were found the most tactile feature. From five different tactile regions 59 % of the respondents found the dots the most tactile. The ‘spades’ were ranked second with 17 % [91]. This may be explained by the differences in the dimensions and shapes of the dots. In case of the investigations done by the ECB, the dots were designed as ‘craters’ with a hole in the centre, while the others were more spheroids.

Appendix 8

Edge modification & holes

A8.1 Introduction

Searching for solutions to assist the blind central banks might look in the direction of edge modification of banknotes and/or the application of holes, often proposed by the blind organisations. Proposals to edge modifications like notching and cutting corners were first mentioned in an unpublished 1980-study of the US Bureau of Engraving and Printing (BEP) [82]. Also the Bank of Canada reported in the early 1980ths on edge modifications like clipped corners in 1982 [10]. Inspiration was and can be found in coin design (Figure A8.1):
- edge profile (outline),
- stamping the coin's edge (edge milling, e.g. edge inscription),
- a hole.

Also modern room keys used in hotels are a source for inspiration. Until today such proposal are not feasible for banknotes.

A8.2 Edge modification

One of the most used design parameter to provide coins with a denomination feature is to create different edge profiles. The National Research Council (NRC) discussed such solutions for banknotes in their report on currency features for the visually impaired [37]. Changing the edge profile of a banknote can be done in two ways: by corner cuts or by edge notches (see Figure A8.2).

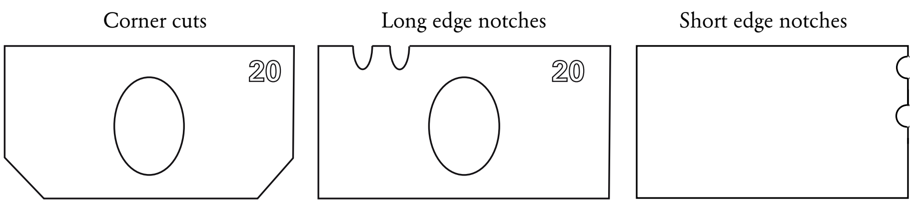
The cut corners or notches could also give an orientation clue. The drawbacks of such solutions were also provided:
- folded corners could be confused with clipped corners,
- concerns in handling and degradation.

Figure A8.1

Inspiration source for banknote edges?
From left to right: one cent Belize (1989), three pence Great Britain (1952), 20 eurocent (Spanish flower) (2002), 25 Egyptian piaster (around 1990), 50 pence Great Britain (1998), room key Frankfurt Hilton (2005).

The idea of clipped corners is first mentioned in a 1982 report of the Bank of Canada: 'Larger denominations should have the fewest corners clipped to minimise the danger of upgrading the notes'. The cuts could be straight or curved and extend from 6 mm to 12 mm along each side. Also the Dutch blind proposed such solutions in 1989 [24, 26, 29]. It was explained by DNB that this suggestion has been made by the blind for many years, but that there are no production machines for such notes. No where in the world one may find such notes. In 2007 the Bank of Canada once more stated: 'Clipped corners are not an option from a circulation point of view.'[79].

Figure A8.2



Three proposals for edge modifications of banknotes. All drawings are exaggerated for illustration purposes. Corner cuts and long edge notches are drawings made by the NRC.

Re-invention of clipped corners

Searching for a solution to make the USD-notes more accessible to the visually impaired, congressman Pete Stark proposed in 2007 to trim the dollar notes on the corners. One dollar note should be trimmed on all four corners, the two dollar note on three corners, the five on two diagonal corners and the ten dollar on two corners on a long side, the 20 on two corners of a short side, the 50 on one corner and the 100 would remain untrimmed [80].

In 2008 a US patent application has been filed proposing such truncated corners, different for each USD-denomination. 'The sequence of the banknotes shall have fewer corners clipped as the denominations progressively increase from USD 1 through USD 50, so that a counterfeiter can not defraud a visually impaired person by clipping additional corners off of a banknote.' Since the idea is not new, the applicant introduces other – also not new – arguments and put his effort in fine phrasing like: 'The USD 1 banknote with its pleasingly rounded four corners will resist becoming 'dog-eared' and should be structurally superior and longer-lived than the current USD 1 banknotes.' [93].

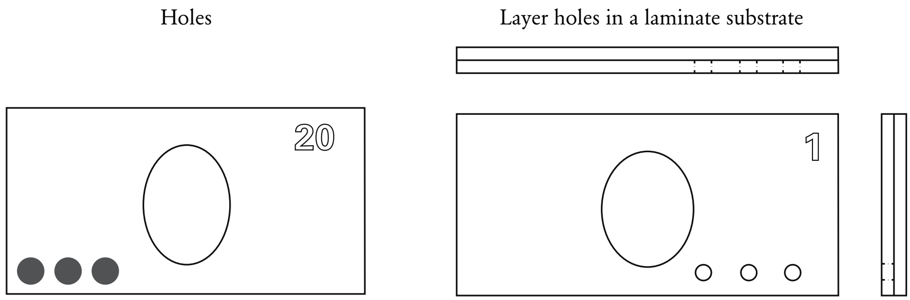
Rounded corners will resist dog-ears

In 2005 a test with euro banknotes with trimmed corners was done by DNB (Figure A8.3). The idea was to come to a higher durability of the banknotes (and not to develop a denomination feature for the blind). The idea of rounded corners is not new and was known in the banknote industry. Still inventors claim this idea, like in the above mentioned 2008 US-patent.

Figure A8.3

Dog-ears are one of the reasons for unfit banknotes. This gave Mr. Hans Broeders of DNB the idea to trim the four corners of a banknote. A test with 10.000 euro banknotes with rounded corners was done in 2005 with 4 different sorting and counting machines. Radius of round corner 7 mm. The conclusion was that process ability of these notes was just as good as with standard euro 10 banknotes and for one machine even better [64].

Figure A8.4



Proposals of the NRC in 1995 to make holes in the note: full holes or partial holes (layers) in one thickness of a laminated substrate.

A8.3 **Holes**

Next to edge modification the blind often suggest to make a hole in a banknote, just as is often done in coins. Banknotes with holes in them are not difficult to produce. Draw backs are durability and public acceptance. The NRC also came with a suggestion for holes in a laminated structure, e.g. in a two layered banknote paper (Figure A8.4). Small raised areas are easier to detect from a background than small holes. That is why holes or depressed areas should be significantly larger than 'positive' tactile patterns like blind marks.

Appendix 9

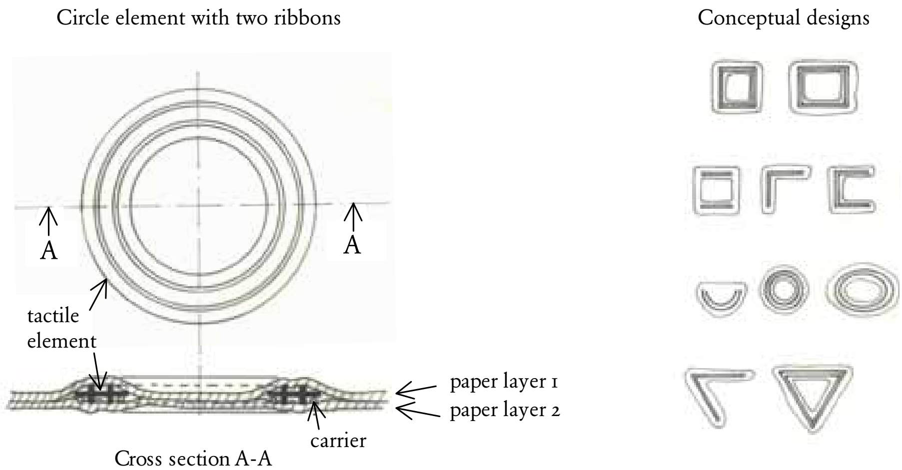
Plastic, metal or carton tactile marks into the paper

On the horizon some other tactile features for banknotes might become available; however these features are not mature enough for the design phase and should first be developed within a separate R&D-project.

Flexible elements into the paper
A different solution for printed tactile elements would be a flexible piece of any kind of material incorporated into the paper. This would overcome 'signal noise' of neighbouring folds. These elements could be made from plastic, metal or paper and are positioned on a carrier from e.g. cotton or a water dissolvable material.
This carrier would be fed into the paper machine. Figure A9.1 is a conceptual proposal for such a feature [22]. The height of the marks would be around 0.1 mm, the same magnitude as the thickness of casual banknote paper. As a consequence, the thickest area in the banknote paper – at the location of the inserted tactile mark – would be around 0.2 mm.

This DNB idea was sent to their patent agency in 1988 for research. Two old patents were found, a British (1909) and French patent (1962), concerning the idea of inserting metal or other pieces like carton in between two layers of paper. A located tactile mark into paper was never claimed, neither was the idea to use such inserts as a tactile mark for the blind into banknote paper. Still DNB decided not to file a patent application on this idea. The idea was discussed in 1990 with Dutch paper maker VHP as a novelty for the new NLG 100. The Dutch paper machines at that time were single layer machines. Still some trials were done with thin copper elements, but the results were not satisfactory. Also the printer was not positive because of paper on-flatness; a maximum relief of 0.02 mm to the paper top would be allowed, far below the trial.
In 2007 a similar idea was mentioned in a report of the National Research Council. This committee suggested a compositional change of the substrate to incorporate new materials in a variety of new innovative ways, like e.g. a paper embedded tactile denominations markings that 'appear on demand' when the note is stretched [85].

Figure A9.1



Circular tactile element made of a material like metal or plastic, to be inserted into the (two layered) banknote paper, including cross section. On the right some more conceptual designs of tactile elements are provided, based on line, squares, circles and triangles.

Tactile pattern inside banknote paper

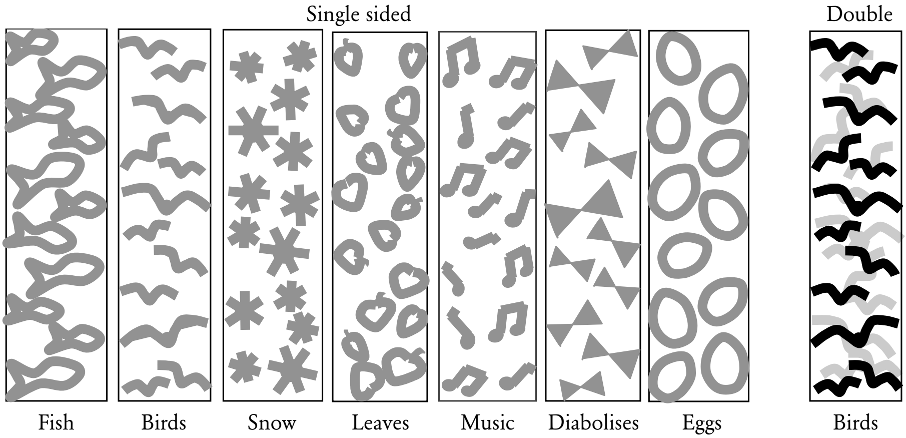
Instead of metal or plastic also a printed pattern could be fed in between the two paper layers as is shown in Figure A9.2. One of the possibilities is to use so called ‘swell inks’, printed on a carrier. This carrier is fed in between the two layered banknote paper. The swell inks will absorb the water in the paper machines and will increase its thickness.

The patterns of Figure A9.2 are inside the double layered paper substrate and should therefore have a strong and simple design. The patterns are different for each denomination; sharp, straight lines are altered with soft, round lines. Each pattern has a simple name and meaning so that they are better recalled.

Shapes could be associated with the colour of the note, e.g. snow in a blue note and leaves on an orange note. Snow and leaves will fall everywhere. For fish and birds there are no borders. Music is universal.

Typical design requirements are:
Random positioning. E.g. maximum distance 6 mm, minimum 2 mm.
- One line width, e.g. 3 mm for all elements.
- Three different sizes of the elements. Large, medium and small.
- Medium is around 7 mm. Large is 10 mm, small is 5 mm.
- Height: around 0.1 mm.

Figure A9.2



Concept of tactile patterns for a series of banknotes. Left: patterns on one side of the carrier. Right: patterns on both sides of the carrier. Elements will partly overlap. As a consequence the height will vary between e.g. 0.1 mm and 0.2 mm. Design by author (2007).

Appendix 10

New intaglio engraving techniques

New intaglio plate making techniques are based on drilling or laser engraving became available around the year 2000. Both are using digital techniques instead of chemical etching. One of the major improvements to the traditional etching is the possibility of a higher relief and more sharp lines, especially relevant for tactile patterns. For both, drilling and laser engraving, different manufacturers offer their own systems and specifications. Purpose of Table A10.1 is to provide a general overview of the improved specifications, while each manufacturer will have its own specific product and production characteristics.

Table A10.1

Characteristics	Traditional engraving	New digital engraving systems	
	Chemical etching	Drilling	Laser engraving
Product			
1. Maximum printed relief	50 µm	150 µm	150 µm
2. Steepness of relief	poor	limited	good
3. A-symmetrical profiles	not possible	limited	good
4. Connection thick/thin lines	not possible	possible	possible
5. Sharp joint crossed lines	poor	good	good
6. Smallest printed dot	0.20 mm	0.15 mm	0.15 mm
7. Shallow lines	not possible	not possible	2 - 4 µm
8. Minimum line width/ tolerance	15 µm +/– 5 µm	10 µm +/– 3 µm	10 µm +/– 2 µm
9. Minimum line width deep engraving	30 µm	~ 20 µm	16 µm

Characteristics	Traditional engraving	New digital engraving systems	
	Chemical etching	Drilling	Laser engraving
10. Micro letter minimum height	200 µm	150 µm	125 µm ?
11. Line pattern, positive, line width	~ 0.04 mm	~ 0.03 mm	~ 0.02 mm ?
12. Line pattern, negative, line width	~ 0.09 mm	~ 0.06 mm	~ 0.04 mm ?
13. Colour density modulation	limited	good	good
14. Intaglio to border (bleeding off)	no	limited	good
15. Register offset - intaglio	+/- 0.75 mm	+/- 0.75 mm	+/- 0.5 mm ?
Production			
1. Additional hand engraving possible	yes	no	no
2. Variable line width keeping width	no	yes	yes
3. Ink retaining structures	poor	limited	good
4. Range of plate relief	25 - 100 µm	15 - 150 µm	15 - 150 µm
5. Reproducibility of the die	~ 96 %	~ 99.5 %	~ 99.9 %
6. Typical lead time for changes	28 days	1 - 5 days	1 - 2 days
7. Overall lead time press ready plate	5 days	5 days	< 3 days

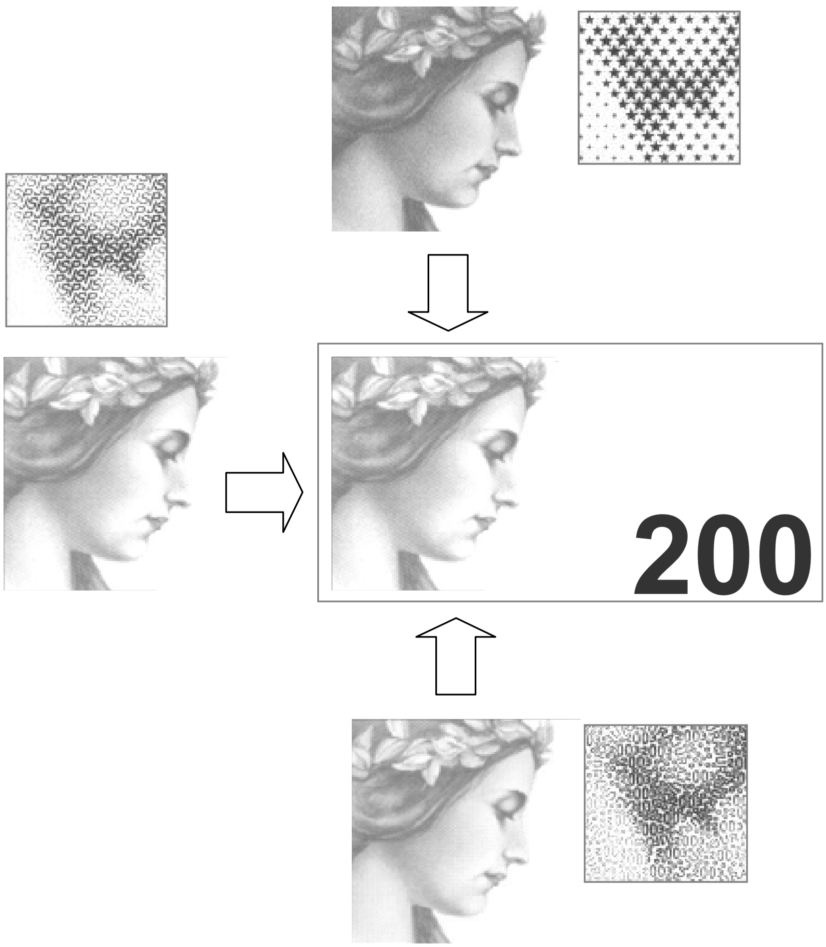
Overview of typical product and production characteristics of the traditional versus digital intaglio plate making [57, 60, 61, 65].

Increased contrast

Main images on banknotes are often printed using intaglio gravure. The new engraving techniques, based on digital techniques, make it possible to increase the contrast of intaglio printing. With just a single colour (or ink), a large gradation scope is reached! Good news for people with low vision, since an increased contrast scope will make images more distinct.

Increased security
Different image techniques, i.e. screenings, provide the possibility of increasing the security of the banknote. For the eye an intaglio portrait composed of two, three or even more different screening techniques will look homogenous, as if it is made of one screening technique (Figure A10.1). Magnifying the portrait will unveil the different screens. Reproducing the image will be more difficult, since the balance between the different screens will be disturbed by the screening technique of the counterfeiter. Not easy to originate, not easy to counterfeit!

Figure A10.1



The portrait is conveyed of three different – and unusual – origination techniques, which should look similar for the human eye. In a reproduction the three origination techniques will drift apart. These pictures are derived from the brochure 'Samples' from Jura (2005). The original idea was delivered by DNB (De Heij) in 2004.

Figure A10.2

Illustration of new design possibilities using digital engraving techniques.
Left: Example of a proposed negative micro text; wide letter spacing and sharp contrast for better legibility! Letter height: around 0.15 mm. Design by author.
Right: Example of connecting thick and thin intaglio lines. The thinnest possible lines are 10 μm, while the thickest lines can be up to any width required (with bottom structures in the thick lines). Design by author.

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