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# Noticeability of Features of Secure Documents

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**U.S. DEPARTMENT OF COMMERCE,** Malcolm Baldrige, *Secretary*

**NATIONAL BUREAU OF STANDARDS,** Ernest Ambler, *Director*

ABSTRACT

A review of the literature on the noticeability of features of counterfeit
bills, primarily British pound notes, is presented. The review suggests
that prolonging the attention paid to a banknote may be a counterfeit deterrent.
Various design options are suggested. A pilot study on the noticeability of
features of counterfeit US dollars is also presented. The study includes both
spectroradiometric measures of the chromaticity and luminance of a set of
counterfeit bills and an identification study. In the identification study,
21 participants selected counterfeit bills from a much larger stack of genuine
bills. They also listed the features they noticed as they made their selection.
Each participant successfully identified about 80 percent of the counterfeit
bills, although only one counterfeit was identified by all participants.
Features noticed included problems with the portrait appearance, lack of detail,
color (both of the paper and the green seal), contrast, and feel. Participants
also made errors with genuine bills, although they noted fewer features and
often mentioned printing press defects.

Keywords:

attention; chromaticity; counterfeit bills, counterfeit deterrent; identification;
luminance; spectroradiometric measures

FOREWORD

This report is one of a series documenting the results of NBS research in support of Bureau of Engraving and Printing Contract No. V-0283-09, entitled "Noticeability of Features of Secure Documents." The report summarizes research conducted from January 1984 to February 1985.

ACKNOWLEDGEMENTS

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## Executive Summary

The overall goal of counterfeit deterrence is to make it more difficult for counterfeit money to pass undetected as genuine currency. A first step toward that goal is to determine what features, if any, of counterfeit U.S. dollar currency are noticed by human observers. Counterfeit currency is a problem presently accounting for around $7.8 million in circulation in 1983, with $64 million seized by the Secret Service before circulation. The advent of inexpensive color copiers is expected to have a noticeable impact on the extent of future counterfeiting. As a result, it is important to determine what features enable people, particularly those with no training in currency handling, to discriminate counterfeit bills from genuine bills.

The present study was designed to explore the question of what features people notice about paper currency, as part of an on-going research effort by the Bureau of Engraving and Printing (other research efforts have been directed toward machine evaluation elsewhere). Two approaches were used to determine human detection abilities. The first was a review of the research literature on counterfeit document detection. The second was a pilot study in which untrained people identified bills as counterfeit or genuine, and indicated the features responsible for their decision. These features were related to physical measures of color and reflectance where possible.

The review of the literature uncovered relatively little research specifically dealing with detection and identification of counterfeits, with one notable exception. Professor Ivor Stillitz conducted 10 years of research on this problem for the Bank of England. His research is reviewed in detail in the present report, in terms of both the methodology used and the results reported. Initially, Stillitz determined that people could discriminate very small differences in color and printing depth and could identify counterfeits based on them. When Stillitz assessed note features remembered by people, he found that they remembered the Queen's portrait, the denomination, and the presence of a signature. He found that obscuration of the portrait significantly decreased people's ability to detect forgeries reliably. He also found that people's expectations played a major role in finding forgeries - when they were told that forgeries were present, they found them, even when all the notes were genuine. In fact, when they received money in a cash transaction simulation, they frequently did not even count it, much less detect the real forgeries present. Despite this result, Stillitz found that in a sorting task, even if people did not identify the forgeries accurately, they still spent significantly more time examining them.

These results led Stillitz to the conclusion that counterfeit recognition could be improved if people were forced to spend more time looking at the note, particularly at the portrait. To accomplish this, he suggested that variations in size, shape, and color should be eliminated between notes, and that the portrait should serve as the primary indicator of denomination.

Stillitz' research is particularly relevant to U.S. paper currency because many of the denomination cues common to British currency such as changes in color,

size, and shape are not used. The portrait, on the other hand, does vary among denominations. U.S. currency would be close to that recommended by Stillitz for maximizing attention except for the placement of the denomination counters. Their position at the four corners of the bill means that no other cue needs to be used to determine denomination. A bill can be used simply by looking at one corner and ignoring the rest of the note, including the portrait and other engravings.

A pilot study was conducted to determine if people could discriminate counterfeit U.S. paper currency from genuine currency when allowed to inspect the entire front of the note. (This approach avoids the problems noted above in which only the denomination counter is examined.) In the study, 21 people who had no specialized training in currency handling examined a set of 102 notes. Their task was to identify each bill as counterfeit or genuine, and state which features were responsible for their decision. At the end of the study, they identified the portraits for common denominations. Physical measurements of chromaticity and luminance were also made.

The results indicated that people identified about 77 percent of the bills accurately. There was considerable variation between people with a range of 40 to 92 percent accuracy in identifying all bills. Four people identified all 22 counterfeits correctly, but only one person identified all genuine bills accurately. Nobody identified all bills correctly. Two counterfeits proved particularly difficult to identify, with errors by about half the observers on these bills.

Despite the similarity in percentage correct identification for the two types of bills, many more comments were made about the counterfeits. Features of counterfeit bills that people noted frequently included problems with the portrait, the color, the contrast, the feel, and the overall detail. On the other hand frequently occurring comments about genuine bills included OK, feels wrong, irregular borders, and printing defects such as blotches and stray ink. Comparison of differences in physical measures of chromaticity and luminance tended to confirm that counterfeit bills had slightly different greens, darker whites, and lighter blacks than genuine bills. Thus, the comment data generally tended to confirm that counterfeit bills had slightly different greens, darker whites, and lighter blacks than genuine bills. Thus, the comment data generally tended to confirm the physical data. The portrait data proved somewhat surprising in that people were only able to identify George Washington on the $1 with any accuracy. Combined with the comment data, these data suggest that people appeared to be more certain of what the quality of the portrait should be, than of whose portrait should be on a specific denomination.

In conclusion, the data from the pilot study indicate that people can identify many, but not all, counterfeits accurately. Some counterfeits are good enough to fool most people. Accurate identification of counterfeits is further complicated by the fact that when people are told to look for counterfeits, they term many genuine bills as counterfeit, often because of real printing flaws. Yet, the features noticed on counterfeit bills tend to be different —

related more to portrait quality, color fidelity, degree of contrast, and feel. As Stillitz had found, people appear to notice something about forgeries that they do not notice about genuine bills, even though they may not use this information to discriminate the two types of bills.

Results from the pilot study and Stillitz' research reinforce the need to increase the amount of time that people spend looking at bills during currency transactions. These results suggest strongly that further research should be done to evaluate the position of the counter relative to the portrait. The effectiveness of centering the portrait between two counters, while removing the counters from the edges of the bill, should be evaluated. Conversely, the effectiveness of increasing the amount of security engraving in the region of the present counter location could also be assessed. In addition, the effects of increasing familiarity with the portraits on all denominations should be assessed. These two efforts should increase the time spent examining the bill and increase awareness of its engraving quality.

The effectiveness of greater color variation on all notes must also be assessed. Color combinations which are readily perceived by people, but poorly reproduced by copiers should be evaluated. The effects of variation in light source spectral composition on the chosen color composition should also be assessed to ensure that inadvertent color shifts do not occur under common light sources. The feasibility of increasing printing depth should also be assessed since Stillitz found that people are quite sensitive to the tactile quality of engraved notes. Other suggestions for increasing the effectiveness of counterfeit deterrence include decreasing the number of very worn bills in circulation to heighten dissimilarity with counterfeits. People in the pilot study commented repeatedly on the difficulty of discriminating genuine worn bills from deliberately worn counterfeits.

In conclusion, data from the pilot study and from Stillitz suggest that people are capable of discriminating counterfeits, but that their ability could be enhanced by some simple design improvements to the note. The changes could increase the amount of time that people spend looking at bills, and thus improve their chances of detecting counterfeits. The desirability of increasing time spent examining currency must be balanced against time lost during currency transactions, however. The cost of increasing inspection time must consider the extent of counterfeiting.

# 1. Introduction

The Bureau of Engraving and Printing has made considerable efforts to design and print bills that are difficult to counterfeit. The design features selected affect the appearance of currency to a marked degree. Yet, although there is much information about design features of genuine banknotes, relatively little is known about the features of counterfeit notes that actually play a role in distinguishing them from genuine notes. What do people notice about counterfeit notes? Can they distinguish them from genuine notes? What features do they use to make this distinction?

The present report is an attempt to determine the noticeability of features of counterfeit and genuine U.S. banknotes for human observers. Two separate approaches are discussed. The first is a review of the research literature on features of counterfeit money. The review summarizes an extensive body of research on the perceptibility of British pound notes. The research on British banknotes is one of the most complete efforts to determine which features of banknotes are noticed and how these features affect the discriminability of forged notes. There does not appear to be comparable research for U.S. paper money. In the second approach, data from a pilot study on the discriminability of counterfeit and genuine U.S. dollar bills are presented along with physical data on the variation in chromaticity and luminance of a selected set of genuine and counterfeit dollars.

## 1.1 Information on Design Characteristics of Counterfeit Bills

Several reports on counterfeit currency were consulted to determine which design features of counterfeit bills tend to vary. These sources also provide general guidelines to the public about which features to look for in identifying counterfeit bills. These guidelines are summarized here to give an introduction to counterfeit money in general and to provide some background for discussing the currency features that participants reported noticing during the pilot study.

Baker (1980) noted the following critical features of bills:

> The portrait should be life-like;
>
> The background lines around the picture should be unbroken;
>
> The sawtooth marks around the seal should be very even;
>
> The serial numbers should be firmly and evenly printed;
>
> The criss-crossing lines in the scroll should be clear and unbroken;
>
> The paper should be strong and of good quality with red and blue threads.
>
> The colors should be clear, and not muddy.

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Harshe (1978) pointed out that use of the intaglio printing process in which paper is essentially forced into the printing plate to pick up the printing ink is very expensive so that counterfeiters avoid it. This process, however, imparts a very life-like quality to the portrait because it creates a third dimension or "depth" to the bill. This "depth" is impossible to create with any other printing method, so that flat, lifeless portraits characterize most counterfeits. A genuine note appears lifelike – the portrait stands out distinctly from the fine lines of the background. In a counterfeit, the background is often too dark, with the portrait seeming to blend right into it. For genuine bills, as noted earlier, the Treasury seal is the right color with even, clear, and sharp saw-tooth points. In the border, the engraved lines are continuous, clear and distinct. These lines are invariably broken and weak on counterfeits. Harshe noted further that U.S. currency is printed with secret ink, which can rub off, unlike the ink on photocopies.

Cooke (1972) pointed out that the borders of genuine bills are engraved with geometric lathes, again to make counterfeiting more difficult. Hand-engraved portraits, lettering, scroll work, and other intricate designs are used to make counterfeit printing more difficult. These engraving features also increase the appearance of sharp, high-quality printing. The serial numbers, Treasury seal, and Federal Reserve Bank designation are overprinted, rather than engraved. Blank areas are left around them to show the quality and consistency of the paper.

Torres (1980) pointed out that most counterfeiters use an offset method of printing, rather than intaglio. Only about 5 percent of the counterfeiters use the more difficult and expensive intaglio process. Torres also pointed out several cues for verifying the genuineness of a bill. These include distinctive paper (75 percent cotton and 25 percent linen); distinctive red and blue fibers that can actually be pulled out of the paper; typographic printing of seals and serial numbers so that they lie on the surface of the paper; and intaglio printing of portrait, signature, series number and complete back. Other features include a match between the Federal Reserve Number and the corresponding letter of the alphabet and uniqueness of each serial number within the same denomination for a given series. Torres pointed out further that estimates of the dollar value of counterfeit bills in circulation ranged from 2.8 million in 1974 to 3.8 million in 1976. Estimates for 1983 were $7.8 million in circulation, with $64 million seized before circulation (Washington Post, 1984). Estimates of the value of bills seized, but not circulated, ranged from 39.2 million to 64 million during the same time period. Estimates for 1983, were $7.8 million in circulation (Washington Post, 1985). Cities with the greatest numbers of counterfeit bills in circulation included New York, Miami, Los Angeles, Boston, and Chicago. Torres noted further that counterfeiting is not a new problem in the U.S., as problems of counterfeited wampum were reported for American Indians. In addition, between 1789 and 1841 as much as $4.4 million in counterfeit bills was in circulation. The problem of recognizing features of counterfeit money is obviously not a new one, despite current advances in printing techniques.

The Secret Service published a document entitled "Know Your Money" (1983) which also provides some helpful hints for recognizing counterfeit bills. In

addition to the points already discussed, the booklet notes that the hairline
of the image in the portrait should be distinct and stand out from the back-
ground. Furthermore, counterfeiters may take a bill of a low denomination,
bleach out the counter (denomination) information, and replace it with a higher
denomination, or they may simply cut out a higher denomination thus "raising"
the face value of a bill. Detecting these changes requires paying some
attention to the design features of the banknote.

Andersen (1975) reviewed some of the characteristics of banknote printing. His
major focus was on the quality of banknote printing as a primary security
device for deterring counterfeiters. His report reviews security devices,
including the principles, techniques, and even the esthetics of security
graphics. As he put it, "The various components of the banknote, its ground
patterns, its lettering, pictures etcetera may be executed so that their quali-
ties are evident and their visual effect characteristic in a way that differs
signficantly from those of other printed matters. And these qualities should,
even to the more or less ignorant, or at least uninformed, public be easily
recognizable so that imitations will 'look wrong' straight away, even at a
casual glance" (Andersen, 1975, p. 9). The note may look simple and be easily
recognizable, yet contain printing of very high precision and detail that is
very difficult to reproduce. Andersen attributes most of the quality of the
printing to the engraving process, which allows for very fine unique details,
as well as for variations in the actual ink color itself. He notes that
(p.12-13) "Very small deviations from the original line and dot structure
count immensely to the forger's detriment. Such tiny changes play a far more
decisive role in the portrait likeness and in the facial expression than similar
changes in the lines and dots would do to the likeness between, say, two
representations of the same landscape." As a result, many countries have used
the portrait as the focal point for their currency.

A review of the literature on counterfeit currency recognition yielded relatively
little information, with one major exception. The Bank of England conducted
about 10 years of research on the perceptibility of features of banknotes--both
good and forged--under the supervision of Prof. Ivor Stillitz. This research
will be presented in detail to provide an idea of its depth and breadth, and
to provide a framework for the pilot study on U.S. currency discussed in this
report.

1.2 Perception Research

In 1976, Stillitz prepared a summary report of his research on perceptibility
of banknote features, entitled "Studies in the Ergonomics of Banknote Design".
He began by noting the following problems in determining noticeable features:
1) Expectancy of finding a forged note is low; 2) Misconceptions exist--i.e.
presence of a thread or watermark (even if an obvious forgery) is taken as
positive proof that the bill is "good"; and 3) People do not normally pay
close attention to features degraded by forgery.

As a result, Stillitz proposed a "Control Model" for understanding and improving
the process of forgery identification and note handling. This model is based
on three separate processes. The first process is that of prolongation.

Stillitz theorized that making denominations more difficult to discriminate from each other would result in more attention being paid to their features.

The second is interference--by which Stillitz meant that cues used for denomination identification should be particularly liable to degradation as a result of forgery. The third is a hybrid approach in which a salient cue such as a number is used for denomination identification, but is placed in an area of the note particularly likely to show the effects of forgery (such as the portrait). Thus, in the hybrid approach, attention should be prolonged for areas which are most likely to be poorly reproduced in a forgery.

Before developing the control model, Stillitz worked on a detection model of currency feature identification. To support the development of this early model, Stillitz conducted a series of experiments designed to determine which features of notes are detected, and to assess the role of different sensory modalities in detection. Thus, this research assessed the role of different senses, such sight, touch, hearing and smell, in detecting forgeries in a series of 26 experiments. In the following section, the results of each experiment will be discussed in turn.

1.3 Visual Capabilities

The first sensory modality that Stillitz investigated was that of vision. His initial concern was to determine which areas are typically looked at on a note. In Experiment 1, Stillitz observed 33 transactions in 8 different locations at a store cash register (till). This indicated that notes were generally placed face-up in the register, suggesting that features of the note's front were critical in extracting information about the bill (such as denomination). It should be noted that the fronts of all British notes currently contain a portrait of the Queen on the right-hand side with a secondary portrait to the left of the Queen and the watermark on the left-hand side. Denomination information is presented both as a number (to the right of the Queen) and as a word (to the left of the Queen). Each denomination is shape and color-coded. Although much of the British currency is still the same that Stillitz used, there have been some design changes since his work was begun. In addition, the ten shilling note which he used in at least one experiment has been withdrawn from circulation, and the one pound note is scheduled to be withdrawn later in 1985. Nevertheless, Stillitz' first experiment provided some baseline information about the way in which pound notes are typically stored (and possibly presented to customers). This information suggests further that it is the front of the bill which is critical and which people place in a position to examine.

In Experiment 2, Stillitz used an "eye camera" to assess free viewing of note slides that were rear projected for 10 sec. He assessed fixation time for 3 observers, and determined that the most frequently observed areas of the note (British pound) were the portrait (35%); denomination text (23%); and signature (13%). In Experiment 3, he measured time to identify note denomination with 4 observers. The time required was almost too rapid to measure. In Experiment 4, Stillitz conducted an eye camera study of forgery detection with 4 observers, with unsatisfactory results, due to unanticipated equipment problems. In

Experiment 5, he assessed the time required to identify a note when presented in different orientations using a tachistoscope. A tachistoscope is a device for presenting visual stimuli which controls presentation time, lighting levels, and size. Stimuli may be either pictures or slides, depending on the device used. Using 8 groups of 2 observers each, he determined that a longer viewing time was needed to identify 10 and 20 pounds notes than 1's or 5's, when the notes were presented in unfamiliar orientations, such as upside down or reversed.

In Experiment 6, Stillitz conducted an interview study to determine the characteristics of 1, 5, 10, and 20 pound notes that people recalled. People were also asked to draw a picture of a 1 pound note. Subjects were divided into 3 categories: low income, high income, and experienced groups. There was no effect of age or sex, but observers who typically handled large amounts of money were slightly more accurate. Nevertheless, bank clerks did not stand out in terms of the amount or quality of information recalled. Of the note features recalled, the portrait, denomination number, and signature were most frequently mentioned. Recall for the Queen's presence was high, but low for specific features of her portrait. Subjects were vague about the visual form of the watermark, the location of the promisary clause (promise to redeem the note at its face value), and the exact signature characteristics. They also had less exact information about the design characteristics of larger denomination notes with 52 percent providing no information about 20's and even being unsure of their color. Sixteen percent, however, did remember the Shakespeare motif on the back of the 20's.

At the conclusion of the first six experiments, Stillitz theorized that the following causes were responsible for what observers noticed and remembered. The first was the salience of the attribute—size, shape, color, portrait, and possibly elements of the denomination and serial numbers. The second was the relevance of the attribute to everyday use of the note—i.e. color as a denomination cue, along with size, shape and possibly serial number. The third was the meaningfulness of the attribute—such as the verbal promisary clause, the portrait of the Queen, the watermark and security thread—attributes associated with the validity and worth of the note. In this, Stillitz noted features of similarity versus discriminability in different denominations. Elements true of only one denomination were poorly remembered, with recall being better for the type of element, rather than the specific nature of the element. Many of these conclusions grew out of the data from experiment 6, which set the stage for much of Stillitz' later research and conclusions. Experiment 6 will be discussed again, in the context of the specific sensory modality assessed, since Stillitz recorded all features of the note mentioned, including tactile, auditory, olfactory, and, of course, visual.

In Experiment 7, Stillitz attempted to assess features of visual recognition memory, by cutting up pieces of 5 pound notes, and presenting these pieces to the observers tachistoscopically. (In many of his experiments, Stillitz used slides as stimuli, but in Experiment 7, he apparently used the actual cut-up pieces of money themselves.) Using this procedure with pieces of notes, Stillitz

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found that only the "5" and the "un" of "pound" were consistently identified as belonging to British currency. In Experiment 8, Stillitz found that presenting the "5" without the characteristic geometric background removed the cue needed to identify it as part of a banknote. He theorized that the geometric patterns were identified as part of a note, even if not recognized exactly. Experiments 9, 10, and 11 dealt with recognizing portions of 5 pound notes. Successively greater portions of a note were displayed. In Experiment 10, these portions were shown to 4 groups of 5 observers each; one with a blurry filter, one a red filter, one a clear filter, and one with no filter. In 6 trials, increasingly greater portions of the notes were shown for each condition. In those conditions with color distortion, more time was required to see greater portions of the note. Thirteen of 20 observers did not identify the note until the fifth or sixth trial. This experiment appeared to support the idea of limited capacity to recognize nonverbal, non-numerical components as part of a banknote. In Experiment 11, when observers were asked to identify note parts in the context of other stimuli, Stillitz determined that exposure of the characteristic geometric pattern, although small, could lead to correct identification of a 5 pound note. This suggested the possibility of a recognition memory for detail.

The next series of experiments dealt with observers' sensitivity to the color of banknotes and to variations from the correct color. In Experiment 12, a paired comparison method was used to assess the perceived genuineness of colors, both blues and greens. Seven notes were assessed: a real 1 pound note, and three notes that were greener and three notes that were bluer. Notes that were marginally too blue or too green were perceived as less than genuine. In Experiment 13, estimation of the magnitude of color variations indicated that observers were less sensitive to changes in green than in blue 1 pound notes. Experiment 14, on just noticeable differences in color (JND's), using the method of constant stimuli with 16 observers, (8 for 1 pound notes, and 8 for 5 pound notes), showed that the JND for 1 pound notes (in green) was slightly larger than one ink unit, while that for 5 pound notes (in blue) was slightly smaller than one ink unit.

Stillitz commented that this series of studies indicates that the average remembered color of the one pound note closely corresponds to the average color of the actual note. Furthermore, notes which are close to that color have a high degree of acceptance, but notes that are too blue have a greater effect on perceived genuineness than notes that are too green. Finally, observers are less sensitive to changes in green than in blue—at least for one pound notes. (Variations in color for the blue 5 pound note were not studied to the same extent.) No colorimetric specifications were given for blue or green, as no measuring equipment was available. Rather, color was created by mixing real note pigments by weight.

Stillitz theorized that the differences were smaller for blue because:
1) people are generally less sensitive to variations in green; 2) the more blue in the ink color, the more similar it is to the 5 pound note; and 3) unique green may be more green than the green of the 1 pound note, so that there may be greater tolerance for a green that is greener than the green of

the note. Unique green is defined as a green which has no blue or yellow in it, and is considered to be perceptually unique (Wyszecki and Stiles, 1967). Stillitz provided no information on the apparent yellowness of the green colors that he used. Nevertheless, this series of experiments indicated that people could discriminate very small shifts in color away from the true note color, at least for green 1 pound notes. Confirmation of Stillitz's results is given in vision experiments by Wright (1969) and others which have found that visual sensitivity is less for small differences around 540 nm (green) than for differences around 490 nm (blue) or 600 nm (orange-red).

## 1.4 Tactile Capabilities

In Experiment 6, Stillitz also recorded mention of tactile information related to note recognition. There were few spontaneous mentions of the tactile properties of the notes, although the following comments were made: new notes were seen as crisp, while old notes were perceived as "grubby" or "limp". Sixteen percent of the observers indicated feeling the Queen's portrait, thread or embossed numbers, while 18 percent indicated that they could not feel the print. Thirty percent of the observers commented that the paper was strong and of good quality. Stillitz commented that the recall for the intaglio properties of the printing appeared low, and often misconceived.

In Experiment 15 Stillitz asked observers to identify notes by feel. He had 68 blindfolded observers separate notes from non-notes, by passing a note from the non-dominant hand to the dominant hand, and then rubbing the thumb across the note twice and putting it down. This imposed a time restriction. A total of 24 stimuli were used in the following categories: new plate-printed paper; old notes; new unprinted paper; and old unprinted paper. The paper was banknote paper and commercially available non-banknote paper in a variety of qualities. The results indicated that "notes" made of new, uncrumpled Nelson-design plate-printed banknote paper were accepted at a comparable rate to genuine banknotes. Unprinted banknote paper that was made "old" had a high rate of acceptance, as did old "Croxley Script" (a commercially available paper that is favored by forgers). Stillitz suggested that oldness and crumpledness decreases the rate of accurate recognition of banknotes. In Experiment 16, Stillitz decreased the acceptability of old Croxley script by using as participants, 48 male members of the general public (as opposed to students). These people were presumably more experienced with money handling. In this experiment, the acceptability of the plate printed note also decreased.

In Experiment 17, no restrictions on the length of time that the "note" was felt were imposed for 16 observers. This change decreased the acceptability of the Croxley paper from 87 percent to 31 percent. Finally, in Experiment 18, with members of the general public, Stillitz found that if prolonged tactile inspection were allowed, not one bank cashier or experienced observer accepted the Croxley script. In each of this series of experiments, a slight order effect was observed, such that forgery paper was more acceptable if it were the first in the series of papers experienced.

Stillitz concluded that use of plate printing and bank paper contributes substantially to the perceived tactile genuineness of a note, if it is new.

The acceptance of "old" forged notes is greater if people have not recently handled genuine notes.

In Experiments 19 and 20, Stillitz experimented with the heaviness of the plate printing, and mixed experimentally printed (but genuine) notes with forgeries. Twelve blindfolded observers participated in Experiment 19, which indicated problems with identifying aged, good notes as genuine. The results in Experiment 20 were inconclusive, with problems of adaptation emerging. Finally, in Experiment 21 Stillitz varied the depth of the plate printing, using 2, 4, and 6 thous, (a measurement of printing depth) as well as plain paper (which has little if any depth in printing). Genuine notes which are printed at a depth of 2.5 thous were also included. Eight observers made paired comparisons to indicate which note of the pair was more genuine. From this, Stillitz developed a scale of genuineness. He found that the probability of acceptance decreased as the note deviated from "normal" thickness. The same stimuli, along with a genuine 1 pound note were used in Experiment 22. Eight observers indicated the genuineness of this set of notes. The results indicated that the real note was seen as marginally more genuine than even the 2 thou note. Stillitz suggests that these results indicate a real capacity for recognizing changes in depth of printing. In Experiment 23 he did a study of the magnitude estimation of plate printing, developing a scale of perceived "roughness" or "bumpiness" as a function of the depth of the plate printing. He found that the perceived roughness increased with the depth of the printing, but in less than proportionate fashion. Finally, he assessed JND's in plate printing with 3 observers, and found that a JND was much less than 2 thou, and that observers had total accuracy on this discrimination.

Based on the series of experiments on tactile discrimination, Stillitz suggested that there appears to be a high degree of sensitivity to variations in plate printing depth. In addition, people appear to have good short-term recognition memory for the special properties of new banknotes. This suggests that tactual properties of forgeries should facilitate, though not necessarily generate, the occurrence of a "something wrong" response. Conversely, genuine notes should facilitate a "something right" response.

## 1.5 Olfactory and Auditory Capabilities

Having assessed observers' recognition, identification, and discrimination capabilities for notes varying in visual and tactile qualitites, Stillitz turned to a consideration of olfactory and auditory qualities that might aid in discriminating good notes from forgeries. In Experiment 6, he had determined that observers reported that new notes have a characteristic, but undefined smell, while old notes do not have such a smell. In addition, observers had indicated that new notes crackle, or have a characteristic sound when crumpled. Stillitz tested observers' ability to discriminate notes on the basis of only smell or sound in experiments 25 and 26. In Experiment 25, 24 observers were tested on their ability to discriminate banknotes from newspaper and printed glossy paper by smell alone. Subjects were not able to make such a discrimination accurately. In Experiment 26, 24 observers were asked to listen to a variety of papers being crumpled, and identify those that were genuine. There was no evidence of any ability to identify genuine bills by sound alone.

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## 1.6 Expectations

In the previous series of experiments, Stillitz determined that visual and tactile cues were useful in discriminating forgeries from genuine notes. These cues are most useful, however, to people who are looking for forgeries. Stillitz turned next to a consideration of the role of expectations in determining forgery detection. In the next series of experiments, Stillitz investigated observers' knowledge and expectations about forgeries. In Experiment 27, he reviewed witness statements about forgeries from forgery trials involving 30 cases with six witnesses and 5 types of forgery. A content analysis of witness statements indicated that they typically mentioned one to three features of forgeries. These generally included general appearance, degradation in color or tone, and problems with thread, serial numbers and feel or texture. Although this approach would appear valuable, the problem was that the witness statements were highly stereotyped, with indications of police prompting, so that these data may not reflect what the person-in-the-street would notice.

In Experiment 6, observers had been asked what they would look for in detecting a forged note. They mentioned the security thread, watermark, serial number agreement, comparison with other notes, feel/material, and design quality. Design quality responses indicated the following characteristics of forgeries: poor quality of printing; blurred writing; writing defects; something wrong with design; and something missing or out of place or proportion. At least 3/4 of the observers stated characteristics likely to identify good quality forgeries.

After evaluating people's expectations about forgeries, Stillitz turned to a determination of whether observers could identify forgeries in a set of mixed genuine and forged notes. The first step was to determine their expectations about forgeries -- would they find forgeries among genuine notes simply because they had been told that forgeries were present? Thus, in Experiment 28 observers were asked to pick out forgeries from a set made up of genuine notes only. The set consisted of 30 one pound notes which varied in wear. Thirty-one percent of the notes were identified as forged, with many observers reporting judgements based on objective variability in the notes. They relied primarily on five features: thread, feel of note, color, watermark, and the Queen's portrait. (Responses about the thread were related to its position on the note, rather than its presence or absence.) Stillitz noted that if people are convinced that forgeries are present, they will reliably find forgery attributes in genuine notes. They appear to be aware of the direction of forgery degradation, but their idea of the limits that distinguish forgeries from genuine notes is poor.

In Experiment 29, observers were asked to detect forgeries in a series of slides presenting genuine and forged notes. The slide was exposed for 200 msec every 3-1/2 sec. Subjects pressed one of six keys indicating the following categories: certain forgery, fairly sure forgery, guess forgery, guess genuine, fairly sure genuine, genuine. Twelve forgeries of one pound notes were used with a quality ranging from very good to very poor. Forty-eight slides were

created from these forgeries. A total of 96 slides was used—48 forgeries and 48 genuine notes—with 15 observers. Under these conditions, forgeries were detected and categorized appropriately. Furthermore, the category ratings given by "untrained" observers for the forgeries were highly consistent with the rating of the quality of each forgery given by Bank of England experts, with no genuine notes taken as forgeries. The attributes of forgeries which led to detection were: 1) Imperfections in color; 2) imperfections in definition; and 3) imperfections in tonal range, with 2 and 3 being marginally more important.

These results led Stillitz to the next experiment (30) on the effect of variations in definition and tonal range on the detectability of forgeries when portions of the note are obscured. He obscured the portrait and other randomly chosen areas, and found that obscuring any part of the note led to a drop in the observer's sensitivity to differences between real and forged notes. The drop in performance was greatest when the portrait area was obscured. Stillitz suggested that the tonal range and/or the quality of fine plate printing may be particularly important in deterring forgeries. For example, people may be especially sensitive to the precise nature of the facial expression in familiar portraits.

In Experiment 31 Stillitz used a more realistic situation in which actual forgeries and genuine notes were sorted. He used 20 five pound notes, 53 one pound notes, and 12 forged one pound notes presented in a predetermined random order with the best forgeries first and the worst ones last. This was done to avoid alerting observers to the presence of obvious forgeries. Ten observers sorted the wad of notes into piles of one and of five pound notes. The idea was to determine if forgery detection would spontaneously occur. No observer, however, made any spontaneous comments, but on debriefing 9 of 10 observers indicated that they believed some of the notes were not genuine, and suggested that about 3 to 6 notes had actually been forgeries. The sorting procedure had also been filmed. Subsequent analysis of the film indicated that observers actually took longer to analyze the forged notes than the genuine notes. This time was longer for all forgeries—even the "good ones"—with the data suggesting that some kind of mental "double-take" was occurring. (Evidently, analysis of the film was unable to indicate what the observers were doing that took more time—just that the process took longer.)

In Experiment 32, observers were again asked to sort money by denomination, with the pile of money including both forgeries and genuine notes. In this study, 7 observers received the "best" forgeries first, while 12 observers received the "worst" forgeries first. This time, they were asked to sort the money into 3 piles: one pound notes, five pound notes, and defective notes (with defective being left unspecified.) Observers again took longer to sort the forgeries. For the first group of observers, 7-8 of the 12 forgeries were rejected (as defective), with observers indicating when debriefed that they had rejected anywhere between 0 and 14 notes. The results were similar to the slide experiment, Experiment 29, with the rejection rate for the forgeries about the same, and an indication that the worse the forgery, the more likely it was to be rejected. For both experiments, it took longer for the observers to sort the forged notes, even if they were judged to be genuine.

In Experiment 33, a more detailed assessment was made of the time to accept and reject forgeries. This experiment was a reaction time experiment, in which observers sorted notes into the three categories given above by pressing the appropriate key. The "time to decide," and "accuracy of the decision" were measured. There was a high correlation between the number of times a forgery was rejected and the rating of the quality of the forgery given by the Bank. Time to accept forgeries was longer that needed than to accept genuine notes. "Time to accept" forgeries decreased, however, when the quality of the forgery increased, but "time to reject" increased for good forgeries. (This implies that it is easier to decide about relatively bad forgeries than good ones, and that this decision time can be measured objectively.) In this experiment, some good notes were rejected as forgeries, but with a longer reaction time than when the good notes were accepted as genuine.

In Experiment 34, Stillitz studied forgery rejection in a role playing situation. He had observers make out a check for 30 pounds and cash it, with the experimenter serving as teller. Six observers received 6 forgeries in their money, while 9 observers received only 1. A major problem was that not all observers counted their money. Of the 4 observers who counted the money, one found no forgeries, one found 1 forgery, and two found 5 forgeries (out of 6). These data suggest that people do not typically inspect each note they receive, and further, that only a minority, even when inspecting, notice quite poor forgeries. Finally, observers noticed forgeries more when more forgeries were included in the packet of money. In Experiment 35 the roles were reversed with the observer now serving as the teller, counting out the notes given in response to the check. There was a much lower rate of forgery detection in this situation.

These data suggest that peoples' expectations of finding forgeries can be manipulated. If they expect to find forgeries, they will classify some genuine notes as forged (see Experiment 28). Yet, if they do not expect forgeries, they may not even inspect individual bills when given a handful of currency. The problem of manipulating expectations will be discussed further in the discussion of the pilot study results.

In reviewing the results for experiments 28-34, Stillitz made the following important points: 1) people's sensitivity to different forgeries, when presented visually, is highly correlated with the Bank's estimates of quality; 2) people rarely judge a good forgery to be as good as a genuine note, even if they think it is genuine; 3) the portrait area appears to have special value as a security device; 4) there does not appear to be any fundamental sensory limitation on the capacity to detect forgeries (with the suggestion that there are some sort of subliminal registrations occurring); and 5) in role playing situations, the probability of noticing something wrong with the forgery is lowest if only one forgery is included with many genuine notes.

Following the preceding series of studies, Stillitz developed his original detection model into a control model. The detection model had focused on the sensory cues used by observers to identify bills and bill characteristics. Central to the control model, however, is the idea that people's detection of important banknote features can be controlled, thus allowing more time to be

spent in the process, and increasing the likelihood of detecting forgeries. His research suggested that the denomination color and numbers were especially important, with recognition memory for detailed features being particularly poor. People appear to have a great capacity for tactile recognition, indicating that high plate printing (which creates depth on the note itself) might be valuable. (The only problem would be wear over time.) Stillitz found no evidence that people can recognize notes by smell or sound alone. Stillitz suggested that a control model could be used to design currency with greater sensitivity to forgeries by increasing the value of specific security features. His central assumption was that information relevant to the identification of the note denomination is always processed and analyzed. The current state of British currency is that there are a multiplicity of highly obtrusive cues to indicate denomination. These relevant redundant cues (RRC'S) include: number, color, size, portrait, and general design. If discrimination time could be prolonged, then it might be possible to force people to pay attention to the engraving quality and other security features. Stillitz suggested that a parallel process was occurring, in which people matched the general features of a note to their expectancies of what a note should look and feel like. Thus, successful detection of forgeries requires the following: increase the probability of the "something wrong" response; (this probability is increased if more time must be spent inspecting the note); increase time spent by decreasing between-denomination cues (reduce relevant redundant cues and thus lower salience); and relate the probability of forgery detection to the time spent to discriminate the note denomination.

Stillitz used the control model as the basis for designing the next series of experiments. In Experiment 36, he conducted a card sorting study which assessed the value of 4 cues—color, shape, denomination number, and denomination text. He measured the discrimination time as the number of RRC's decreased; and the relative potency of the 4 selected cues when presented in isolation. Stimuli were cards representing 1 and 2 pound notes, with specific cues for each denomination. One pound notes were represented by one or more of the following: green, rectangular, 1, and ONE; while 2 pound notes were represented by: blue, square, 2, and TWO. There were 32 sorting conditions for the experiment plus two extras: 1) observers sorted blank cards into two piles to provide a baseline measure as well as some practice; and 2) observers sorted cards with inappropriate cues (such as 1, TWO) to provide a measure of the effects of distraction. Each card in the main experiment could have from 1-4 cues for denomination. Subjects then sorted the cards into two piles. Stillitz found that discrimination time decreased systematically as the number of RRC's increased from 0 to 3 (4 cues on card), with the time for 3 RRC's about 80 percent of that for no RRC's. The greatest reduction in time occurred between 0 and 1 RRC. The most efficient cues, with the quickest discrimination, were color and numeral (about equal) with numerical text next, and shape last.

With no redundant cues, numerals were somewhat more efficient than color, but with redundant cues, color appeared to be superior. Stillitz suggested that these results indicate that the number of relevant redundant cues can safely be reduced. (It is interesting to note that US currency has a greatly reduced number of RRC's compared with British. There are no color or size cues—rather the cues for denomination are numerical and design only.)

In Experiment 37, Stillitz conducted a preliminary test of the prolongation hypothesis. He used notes of two denominations as well as forgeries, and presented pairs of notes to four groups of 9 observers each. The discriminability of the genuine note was deliberately varied by changing the number of RRC's included on it. Stillitz hypothesized that the probability of forgery detection would increase as the discriminability of the genuine note decreased. In one condition he removed the lower left denomination guilloche (an engraved design embellishment), while in another he presented 10 shilling notes in the color of the one pound note. Four forgeries, varying in quality, were used. He found that observers were better at detecting forgeries when the guilloche had been removed from the genuine note, than when it was presented in the wrong color. They were also better at detecting poor forgeries, and got better as the number of redundant cues (RRC's) in the genuine notes were reduced. There was no indication of increasing confusion between the two genuine notes for the various cue change conditions.

In Experiment 38, Stillitz did a more thorough test of the prolongation hypothesis with a set of 128 slides of specially designed experimental notes. To create this series of slides, Stillitz used both 1 and 5 pound notes, and used 5 pairs of notes with varied elements. These differed in shape, size, color, denomination text, and numerals. He also created "forgeries" of each special note by: 1) altering the color value by changing the camera stop; and 2) photographing the note through gray mesh, which degraded the sharpness, and altered the color value slightly. A total of 40 observers participated in the study. Unfortunately, the results were inconclusive because the backgrounds were varied inadvertently for some of the forgeries. As a result, the experiment was repeated with masked backgounds (Experiment 39). Stillitz found that the reaction time was longer (about 2 sec) for stimuli with five redundant cues. It was shorter (about 1/2 sec) if there were no forgeries among the stimuli. In Experiment 40 he assessed discrimination time for the different genuine notes only (no forgeries presented). He found that as the note design similarity increased between the two notes, reaction time increased slightly. Thus, in condition 5 the two denominations were very similar in size, shape, color, format, and orientation. They differed only in denomination text and numbers, with the portrait's left ear visible on the one pound note, but not on the five. In condition 1, everything differed. Stillitz found generally that the predictions of the prolongation hypothesis were not verified with statistical significance. Although the trend was in the right direction, the effect was small compared with the variability between observers.

In Experiments 36 through 40, Stillitz observed the effects of varying the number of salient cues on banknotes with a set of specially designed notes. He found that he could control the amount of time needed to identify a note depending on the number of cues for denomination presented. The results were most conclusive when people were asked to discriminate genuine notes from forgeries (even when the "genuine" notes had been specially designed for the study and were not in general circulation). The results were less conclusive for situations in which people were asked simply to discriminate between two genuine notes. Nevertheless, this series of studies left Stillitz with the conviction that the number of cues on a banknote is a critical feature in

controlling the amount of time spent inspecting it (and thus providing an opportunity for detecting counterfeited notes).

In "A Review of Perception Research" (1978-1979), Stillitz reviewed a later series of studies intended to delineate further the role of perception in the noticeability of features of notes. Since this review provided much less detail about the experimental procedures followed in the research, only the results will be discussed here.

In this series of studies, Stillitz explored stimuli similar to the control notes discussed earlier. At this time, he focused on variations in the actual design of the notes, particularly the portrait and color. His stimuli included variations in note design such as: numeric notes; hybrid notes; the "green" Queen (in which portraits for different denominations differed in color as well as in design); and hybrid notes in which the placement of the numeral varied relative to the portrait. Results with the original hybrid notes indicated that placing the numeral next to the portrait masked the portrait. Use of an improved hybrid note indicated that people are sensitive to changes in expression and color of the portrait, but that numeral position can affect the noticeability of the portrait. Typically, reaction time or accuracy of identification were used as response measures. Based on results with these various designs, Stillitz suggested that each denomination should be characterized by a different portrait and that the numerals should be low in salience (or attention-getting power). He found that placement of the numeral to minimize its salience created some difficulties, because when a single one was placed near the portrait it tended to mask the portrait. If it were placed too far away, people tended not to look at the portrait, so that its special engraving qualities were overlooked. Stillitz suggested that if color differences between portrait and numeral were maintained, then perhaps the numeral could be placed close to the portrait.

Stillitz also tried to conduct a series of eye camera studies to assess which features of the note people examined. The studies were an attempt to determine whether the denomination color should cover a greater part of the note's surface or be restricted to a limited portion. Despite the promise of this approach, this series of studies produced inconclusive results due to equipment problems. In another, more informal study, Stillitz observed 200 note-handling events in 6 busy stores. He noted that notes were stored flat; that they were typically unfolded and presented flat to the cashier; and the location of the notes in the cash register served as an important cue. Notes currently appear to be sorted by color and size.

In another report, Stillitz discussed the potential advantages and disadvantages to special security devices contained in the banknote to discourage forgery. (For U.S. currency such devices currently include the red and blue threads, while for many European currencies, these devices include a watermark and a metallic security thread.) Stillitz noted that special security devices are intended to be as a deterrent to forgers. They can be held in reserve for addition to the currency at short notice. Along with these special additions to the banknote, the security devices can also be qualitative, such as the

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overall clarity of the print on the note or the lifelike expression of the portrait. Such devices are often overlooked because they are used so frequently, but as Andersen (1975) pointed out, they can be some of the most effective deterrents for everyday use. One feature of specially added security devices is that they can be used as absolute indicators of the genuine nature of the note or bill. A drawback to this use is that if the device is present, however poorly reproduced, its presence may be taken as certainty that the bill is genuine, even if its engraving qualities are so poor as to be laughable. As a result, decisions about the genuineness of a note may be made on the presence or absence of a special security devices, rather than on its perceived validity. Thus a very poor counterfeit may be accepted simply because it has a security thread, watermark, or other recognized security device. Stillitz commented that high quality printing suggests genuineness while the presence of security devices, however, poorly done tends to confirm genuineness. A successful simulation of a special security device can be very deceptive, as people may check only for its presence and not for other engraved characteristics of the note. In addition, the special devices now are in the paper itself and may not be noticed in actual practice.

Stillitz commented on several areas in which further research on banknote design and perceptibility is needed. These areas include: need for better evaluation techniques; determination of the perceived relationship between the back of the note to the front; assessment of the effects of security devices in counterfeit bill detection; and evaluation of the effects of variation in factors such as design content outside the portrait area, numerical location, size, and shape. Because there is a problem with numerals near the portrait which tend to mask the portrait and compete for attention, one might manipulate the relative salience of the numeral and the portrait to study the masking effect. The masking effect could decrease as the salience of the numeral relative to the portrait decreases.


1.7   Recommendations for Banknote Design

Although there is a need for further research on the effects of specific design variations on banknote salience, the results from this series of experiments, combined with the earlier experimental data were strong enough to allow Stillitz to draw some useful conclusions about banknote design. Stillitz recommended that:  notes should all be the same size and shape; they should not differ only in color; differences in major features should be minimized; denominations should not be totally dissimilar; overall shape should not be the cue; and attention to denomination should be maximized. Stillitz suggested that the portrait is a most valuable device for presenting the quality of the banknote since some of the best engraving is used to create the portrait.

Stillitz noted that a number of questions remained unanswered in his research. The qualities needed in the second portrait on the front of the note remained unclear, as did the relationship of the back of the note to the front. In particular, the role of a vignette for the second portrait was not defined, along with the need for portraits of people in this area. Although geometric/ abstract material can lack memorability, it may be important in indicating

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value and worth.  In fact, notes appear to require handwork and pictorial
matter to indicate worth.  The use of several colors is appropriate, but they
should be chosen so that the juxtaposition of colors makes degradation more
noticeable, and enhances contrast.  The eye's ability to make fine color
discriminations should be used to greater advantage.

Based on ten years of research on the perceptibility of banknotes Stillitz was
able to generalize about the design characteristics which appear to increase
the likelihood that a forgery will be noticed.  He provided the following
guidelines:

1)  Make the back and the front of the note equally difficult to forge.

2)  Make portraits the same color, but use different people.

3)  Use distinctive characteristics for note fronts and backs.  They should
    differ by conceptual cues such as historical age or relation to British
    Royal Family.

4)  Do not vary color outside the portrait area between denominations.  The
    general color pattern of the backs of the denominations should be different
    from the fronts.

5)  Features other than the portrait which indicate denomination or side of
    the bill should have low salience.

6)  Make the general impression of the color the same.

7)  Do not use lithography and plate printing to create the same kinds of design
    elements, as their quality differs, and may create the impression of forgery
    when used in the same place.

Other discussions were related to design content.  Stillitz made the following
suggestions:

1)  Use a representational form with expression or atmosphere.  This shows the
    qualities of banknote printing.

2)  Use few visual elements.  These should be simple and delineated.

3)  Use design content (including geometrical work) to link portraits.

4)  Make the public aware of the theme of the banknote.

5)  Define the desirable properties of the note content through basic and
    applied research.

6)  Use the numeral and denomination text as secondary targets to focus atten-
    tion on the printing quality.

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## 1.8 Relevance of Stillitz' Research to U.S. Currency

Stillitz' work suggests a number of ideas which are relevant to the design and evaluation of U.S. currency. First, there is probably little need to do further work on olfactory or auditory cues for detecting forged or counterfeit money. Second, people have the ability to make very fine tactile and color discriminations not only in a psychophysical laboratory study, but also with actual currency. There is "something" people notice about forged notes. For some, as-yet unclear reason, it takes longer to make decisions about forged notes — even decisions as easy as sorting notes by denominations. Stillitz' later research attempted to sort out the cues responsible for this difference. Even though the studies were not definitive, they point out the need to do multidimensional research, in which the input from more than one type of sensory awareness is assessed.

Future work might usefully examine the interaction of color, line quality, and feel in contributing to the sucessful detection of forged banknotes. In this approach, the role of acoustical and olfactory cues could conceivably become more important, even though in isolation these cues appear relatively ineffective. It is more likely, however, that the effectiveness of those cues shown to be effective in isolation, namely, color, overall appearance, and tactile quality, might be increased.

This tack certainly appears to be the approach followed by Stillitz. His work with the control model and the hybrid notes strongly supports the attention-getting value of the portrait, although it only begins to suggest why this occurs. His research also indicates that it is possible to manipulate the ability to discriminate both in speed and in accuracy between different denominations by varying the number of cues on a note (such as color, size, and graphic characteristics). This manipulation is also sucessful in altering the recognizability of "forgeries" designed from such hybrid notes. In sum, Stillitz' research points out that it is possible to vary the detectability of forgeries by varying the design quality of "genuine" notes. The most successful variations appear to be related to the color, portrait, placement of the counter, printing depth, and number of denomination cues on each bill.

Any body of research that is as comprehensive as that conducted by Stillitz will necessarily have implications for the design and evaluation of other currencies. Although Stillitz' work was conducted with British pound notes, primarily denominations of ones and fives, it is useful to assess its relevance to the noticeability of counterfeited American dollars.

In the following sections of the present report, a pilot study on the noticeability of U.S. dollar notes is discussed. This study bears some resemblance to a number of Stillitz' studies. Where common results occurred, they will be pointed out. Physical measurements of the chromaticity and luminance of a set of counterfeit bills are also presented to provide an indication of the variability to be expected. Finally, Stillitz' recommendations are reviewed for their relevance to U.S. banknote design.

## 2. Approach

### 2.1 Stimulus Material

A set of 108 counterfeit U.S. dollar notes was obtained from the Secret Service. The Secret Service had seized these bills in New York, Miami, and Los Angeles, (cities which have a large number of counterfeits in circulation), in 1982. An attempt was made to get as many different types of bills as possible, in the following denominations: $10, 20, 50, and 100, since these are counterfeited far more frequently than $1 or $5's. (In fact, the final sample contained relatively few $10's.) All bills had been in circulation when they were seized. They were stamped "counterfeit," on both sides, although some bills did not have "Counterfeit" stamped on the front. These later bills were selected, since they were to be used in a pilot study in which genuine currency was to be discriminated from counterfeit bills. Throughout the following discussion, all bills are identified by the last four digits of their serial number, denomination, and category (genuine or counterfeit).

All the counterfeit bills were then measured with a spectroradiometer to determine the extent of variation in chromaticity and reflectance in 6-8 locations on the bill. Spectral measurements were made with a telescopic spectroradiometer. Illumination was provided by a source developed especially for this purpose, consisting of a small 12-volt spotlight with a piece of diffusing plastic in front of it. This light was powered by a voltage-regulated DC source, and mounted directly above the spot being measured. The exact position of the light source was chosen and controlled to minimize random errors. The light source itself had a chromaticity of about $(x, y) = (0.453, 0.419)$ or $(u, v) = (0.254, 0.353)$. While light was incident along the normal to the spot measured, the spectroradiometer was aimed at 45 degrees from the normal, so that the spectral measurements had a 0°–45° geometry. For practical purposes, this means that the specular component of reflectance was excluded, and the inks were seen at their blackest and most saturated. The spectroradiometer was positioned and focused to measure a spot about one mm in diameter (elongated on the banknote because of the 45° viewing angle). The 1-mm spot size can be considered "quite small" and is much smaller than could be achieved with older techniques; nonetheless, the measurements which are termed "green seal" and "black letter" many involve some variable incursion of the un-inked paper into the measurement spot.

All measures were made relative to a reflectance standard with a luminance of about 695 fL. These included: the back lathework near counter upper right; the front lathework near counter, in the upper right; the white area on the front near the serial number (without the back of the bill showing through); the green seal; the right center background area of the portrait; the black of the Federal Reserve Bank letter; the green seal plus black lines; and the white area near the seal plus black lines. Only one measure of the back of the bill was taken—all other measures were of the front. (Additional measures were taken of the seal area because it appeared that the dark areas of the denomination text were darker on counterfeits than on genuine bills.) Similar measures were taken for a limited set of genuine bills, as well.

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The spectroradiometric measures were converted to CIE chromaticity coordinates and then graphed in the 1960 Uniform Color Space (uv) to provide an indication of the variability in counterfeit bills.

The CIE chromaticity system provides a means for specifying color using three primaries or "tristimulus" values. The three tristimulus values are discussed from color matching data of a "Standard Observer" (Wyszecki and Stiles, 1967). Because the three tristimulus values must sum to one, it is possible to determine two values, x and y by convention, and derive the third mathematically. As a result, the CIE chromaticity diagram is a two-dimensional diagram on which the x and y coordinates are plotted. These two coordinates specify the amount of red (x) and green (y) in a match. Unfortunately, the CIE x,y system does not represent all perceptual differences between colors accurately. Uniform color systems such as the u,v system used here, were developed to allow one to plot color differences as they would be seen. Thus, differences of the same units between two sets of colors should be perceived as equal in u,v system but may not be in the x,y system. As a result, the u,v system was chosen to demonstrate differences between measured chromaticities of counterfeit and genuine bills.

Measures of luminance were converted to Munsell Value units to provide an indication of reflectance. Munsell Value was used to represent the reflectance of bills. The Munsell color system specifies colors with three dimensions -- hue, chroma (saturation), and value (lightness). Value represents the "lightness" of a particular color. The Munsell system is another system developed to allow ordering of colors in a perceptually meaningful manner. Value units thus represent differences in lightness which can be perceived.

2.2 Pilot Study Design

The pilot study was designed to be an initial assessment of the discriminability of counterfeit currency when mixed with genuine currency. It was intended to provide some baseline data of the ability to select counterfeits from genuine bills, and to provide an idea of some of the reasons underlying this discrimination.

A set of 80 genuine bills was obtained from the Bureau of Engraving and Printing. Four denominations were used--10, 20, 50, and 100--in three wear categories-- good, bad, and very bad. Wear category was determined prior to the experiment by the Bureau of Engraving and Printing. A set of 22 counterfeits was selected from the larger set of counterfeits described previously. This set included 3 $10's, 6 $20's, 6 $50's, and 7 $100's. These bills were selected to represent a range of wear, as well as to minimize obvious indicators of counterfeitedness. A total of 102 bills were used in the study. These bills were randomly divided into 3 groups of 34 bills each, simply to give each participant several stacks of money such as might normally be experienced during money counting.

During the pilot study, each observer was brought individually into the NBS Illumination Color Laboratory. Light levels were maintained at about 40 fc (36 fl). Illumination was provided by cool white fluorescent tubes, located about 2.5 m above the viewing surface. The surface itself was a piece of light grey cardboard located on a table. The observer was seated in front of

this table and given the instructions (see table 1 of the Appendix). During
this time, the experimenter randomized the bills in each of the three stacks.
The very first bill was deliberately selected to be a very poor counterfeit so
that people would be somewhat familiarized with counterfeits. This procedure
was adopted after one of the first observers identified the majority of bills
as counterfeit. After completion of data collection with this person, the
procedure was changed to provide some initial, informal familiarization with a
noticeably poor counterfeit bill.

Each participants selected one bill at a time, decided if it were good or
counterfeit, and if he or she were sure or unsure of the decision. Viewing time
was limited to about 10 sec. Participants then handed the bill to the
experimenter and gave the reasons for their decision. No time restrictions
were imposed on their comments. The experimenter recorded each decision and
comment. Since only one bill was in view at a time, a participant could not
compare bills with each other. The experimenter did not provide any feedback
about the judgements, either, although reassurance was provided that people
were doing fine. At the end of each of the three stacks of bills, the
observer was given a chance to rest. The whole process took about 1 to 1-1/2
hours, depending on the observer. (Some observers made many comments about
every bill—others made relatively few.)

A total of 21 people participated - 13 males and 8 females. The participants
included 9 professionals, 5 secretaries, 2 technicians, 3 students, and 2
housewives. Two of the participants were color defective (as determined by
the American Optical H-R-R color vision plates), but no other vision problems
were reported. All participants were volunteers, with no specialized training
in currency handling.

After participants had viewed all the bills, they provided general comments
about the features that they noticed, the importance of these features in
their decision, and an indication of their experience with money handling in
general, and counterfeit bills in particular. They also named the person
whose portrait appeared on U.S. paper currency, including $1 and $5's as well
as the four denominations used in the pilot study. Finally, they were shown
several counterfeit and genuine bills and given a chance to compare them.
General guidelines as given by the Secret Service on spotting counterfeit
bills were also discussed.

2.3  Background—The Problem of Analyzing Detection Data

In the present study, participants examined notes that were a mixture
of genuine and counterfeit bills. Their task was to detect the
counterfeit bills in each stack of money. For each bill presented,
there were four possible responses:

> 1.  The bill is a counterfeit and is correctly called counterfeit by the
>     subject. This is a "correct detection," or simply a "hit."
>
> 2.  The bill is counterfeit but is called real by the subject. This is an
>     incorrect rejection or a "miss."

3.  The bill is not a counterfeit but the subject says it is. This is an incorrect detection, or simply a "false alarm."

4.  The bill is not a counterfeit and is called not counterfeit by the subject. This is a "correct rejection."

Problems of this type, concerning the detection of something that might or might not be there, have been studied extensively under the heading of "Theory of Signal Detection" (TSD). TSD had its origin in the development of radar, but has also been used to deal with detection of sounds and lights by humans (see Jeffress, 1964). While the theory of signal detection will not be discussed in detail here, some basic ideas from TSD can help to analyze the counterfeit identification data and give insight into the whole problem of counterfeit detection. The most basic of these ideas is that if the task is a hard one, false alarms are unavoidable, and must be dealt with in the analysis.

When an observer is presented with a number of bills, each response falls into one of the four categories, so that the result is a count of hits, a count of misses, a count of false alarms, and a count of correct rejections. Simple arithmetic imposes two constraints on these numbers, for

(no. hits) + (no. misses) = (no. counterfeits presented)

and

(no. false alarms) + (no. correct rejections) = (no. real bills presented).

Thus, only two of the four results are independent numbers. It is common to define "hit rate" = (no. hits)/(no. counterfeits) and "miss rate" = (no. misses)/(no. counterfeits). Also, "false alarm rate" = (no. false alarms)/(no. real bills) and "correct rejection rate" = (no. correct rejections)/(no. real bills). The constraints imposed by arithmetic then become

hit rate + miss rate = 1.0

false alarm rate + correct rejection rate = 1.0

Hit rate and false alarm rate are usually taken to be the variables of interest, with the other two rates implicit. Although the primary parameter of interest is the observer's "ability" to detect counterfeits, two numbers are obtained that relate to this ability. The extra degree of freedom relates to the observer's criterion. If the observer chooses (or is instructed) not to call something a counterfeit unless he or she is really sure, then the hit rate and the false alarm rate will both be low. If the subject chooses to accept as a counterfeit anything that looks minutely suspicious, then both the hit rate and false alarm rate will both be higher. If the hit rate is equal to the false alarm rate, this implies chance performance.

Regardless of criterion, the observer can show "ability" by giving a hit rate greater than the false alarm rate. (Hit rate less than false alarm rate would indicate ability compounded by a desire to give the wrong answer.) The effect of criterion can be assessed by asking an observer to be more (or less) certain that he/she has detected a counterfeit. A sequence of trials done by the same observer at several criterion levels would give a set of differing false alarm rates, each with an associated hit rate.

A graph of hit rate versus false alarm rate from such an experiment is called the "Receiver Operating Characteristic" or "ROC curve." It has the general appearance of the upper graph in figure 1. While the data in this figure are hypothetical, the common features of all ROC curves are displayed:

1. The graph is square. The curve passes through (0,0) and (1,1), since the strictest possible criterion would result in zero hits and zero false alarms, while the loosest criterion would be to press the button on all trials.

2. The diagonal from (0,0) to (1,1) represents chance performance. That is, hit rate = false alarm rate implies that the probability of the observer's responding was independent of the presence of stimulus.

3. If the subject is making the best effort, the curve will rise monotonically from (0,0) and across the graph. That is, a loosening of the criterion should increase both the hit rate and the false alarm rate. Any deviation of data from this rule must be viewed as random error.

4. For performance above chance, the curve will lie above the diagonal.

5. While many textbook ROC curves are symmetrical about the negative diagonal from (0,1) to (1,0), it is not necessary that this be so.

6. If a second ROC curve were generated by altering the stimulus, or by using a different observer, a higher hit rate at a given false alarm rate would mean better performance at that false alarm rate. More generally, when a signal is highly detectable to a subject, the ROC curve will be high for all false alarm rates, meaning that it rises steeply from (0,0), and then bends over rather sharply near (0,1). A barely detectable stimulus will give a curve near the diagonal. This is illustrated by the family of ROC curves in the lower graph of figure 1.

7. ROC curves can be used to compare different stimuli for detectability or different observers ("receivers") for performance. We now see, however, that it is not meaningful to compare two observers on the basis of hit rate alone. To say that Subject A performed better than Subject B because A caught 80% of the counterfeits presented while B only caught 30%, would be completely false. By a change of criterion, B could raise his/her hit rate to 90% or 99%. What we need to know is the relationship of hit rate to false alarm rate for each observer,
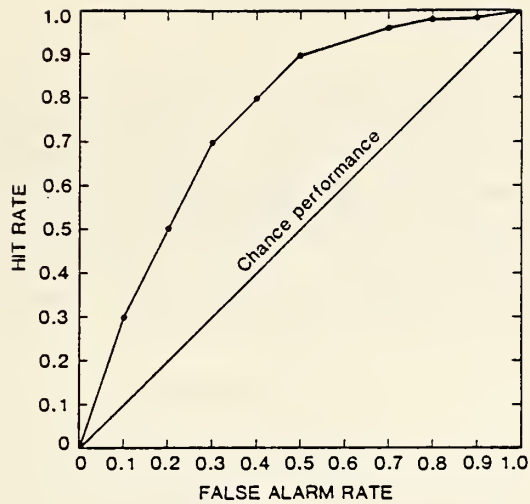
Figure la. An ROC curve from an hypothetical experiment in which a person has been asked to detect a brief tone. The stimulus and the person are the same for all data points. Only the observer's criterion changes from point to point. An experimenter can affect criterion through instructions.
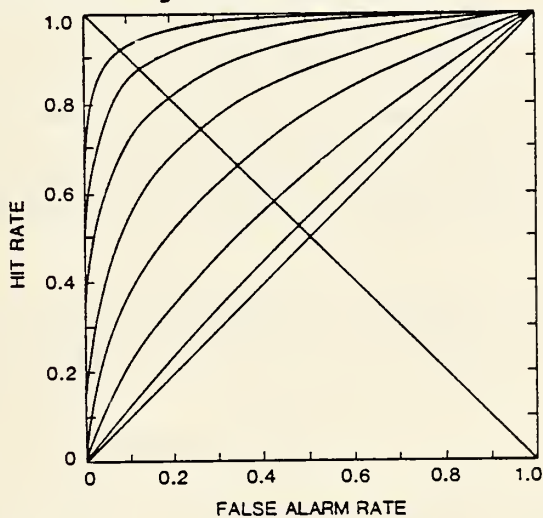


Figure lb. A family of ROC curves corresponding to stimuli of differing detectability (after Jeffress, 1964). These curves were derived from a theoretical model of detection of sounds. They show how the ROC curve becomes higher and more angular as the signal is made more detectable. Analogous data for other types of detection experiments might have given curves which would differ in exact shape.

Figure 1. Hypothetical ROC curves showing effects of shifting criterion and stimulus detectability.

and this is what the ROC gives us.

8. For practical work, it would be desirable to reduce an ROC to a single number, a measure of overall detectability or performance. One such measure is simply the area under the curve. Any such number derived from the entire ROC can be called a <u>criterion-free</u> measure of performance.

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## 3. Results

### 3.1 Overview

Results from the pilot study include: the participants' performance in identifying counterfeit and genuine bills; performance on individual bills; comments about individual bills; overall comments about the decision process and features noticed; and spectroradiometric measurments of counterfeit and genuine bills. Data for each type of result will be discussed in turn.

### 3.1.1 Detectability of Counterfeits

The first set of data to be discussed is the frequency of detecting counterfeit bills in the stack of 102 bills. Table 1 presents data on decision frequencies for each counterfeit denomination, as well as for the whole set. In this table, C refers to identification of the bill as counterfeit, and R refers to identification of the bill as real (genuine). Thus, C/C means counterfeit identified as counterfeit, C/R means counterfeit identified as real, R/C means real identified as counterfeit, and R/R means real identified as real.

Table 1 presents the raw data for each observer for the task of detecting counterfeit bills in a series of mixed counterfeit and genuine bills. From these data, it is readily possible to compute a single false alarm rate and a single hit rate for each person. The data are plotted in an ROC format in figure 2. The number by each point identifies a specific observer's performance. While these are not appropriate data for plotting an ROC curve in the ordinary sense, using this format provides useful information about overall detectability of counterfeits and the variability between observers.

If all observers were equally proficient at detecting counterfeits, but operating at different levels of an internal criterion, the data would indeed follow a curve with the typical appearance of a Receiver Operating Characteristic. This was not the case.

Nevertheless, we can observe that:

1. Observers 3 and 4 operated at the same false alarm rate, as did 16 and 18; 9, 11, and 20; 2 and 7; 1, 14 and 17. In these cases, it is clear that observers did not perform equally well; observer 1 did better than observer 17, for example.

2. Observer 4 performed better than observers 5, 11, 16, 18, and 19, since observer 4's ROC curve must proceed upward monotonically from the known point.

3. A rough surmise can be made of the ROC curve for a typical observer in the group, the particular stack of counterfeit and genuine bills, the specified lighting conditions, and the overall level of training. This estimated curve, fit by eye, is indicated on figure 2.

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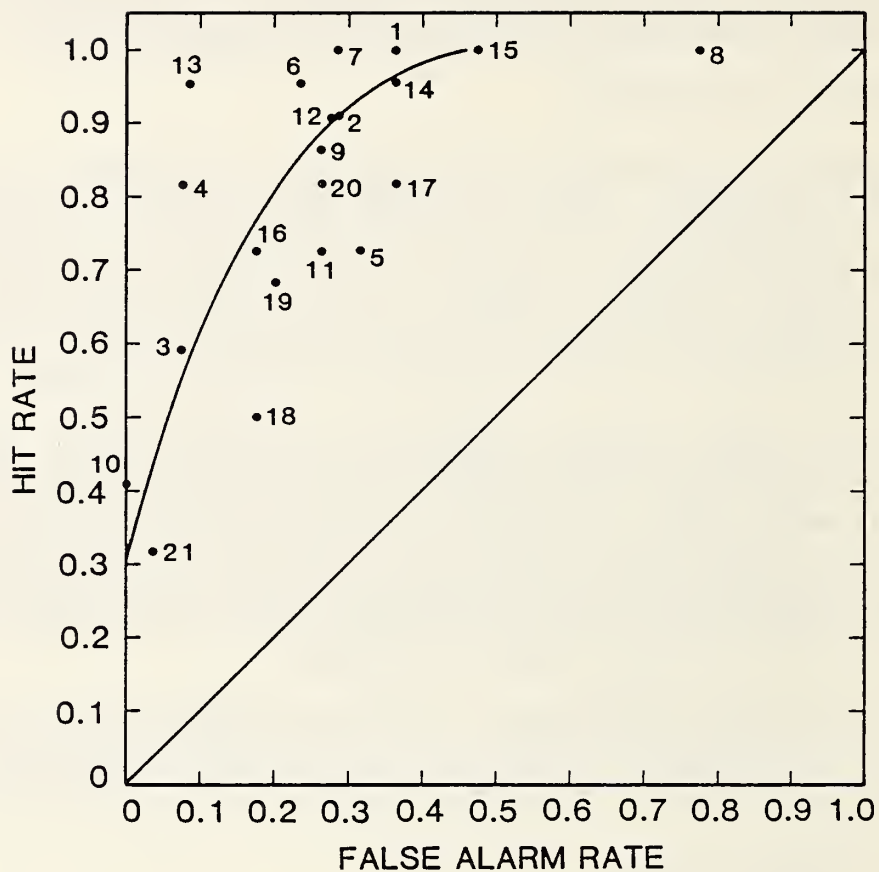
Figure 2. Detectability of counterfeit money for 21 observers presented in ROC format.

Table 1- Observer Decisions about Counterfeit and Real Bills

| Observer | Sex | C/C | C/R | R/C | R/R | Total Correct |
|----------|-----|-----|-----|-----|-----|---------------|
| 1 | M | 22 | 0 | 29 | 51 | 73 |
| 2 | M | 20 | 2 | 23 | 57 | 77 |
| 3 | M | 13 | 9 | 6 | 74 | 87 |
| 4 | M | 18 | 4 | 6 | 74 | 92 |
| 5 | M | 16 | 6 | 25 | 55 | 71 |
| 6 | M | 21 | 1 | 19 | 61 | 82 |
| 7 | M | 22 | 0 | 23 | 57 | 79 |
| 8 | M | 22 | 0 | 62 | 18 | 40 |
| 9 | M | 19 | 3 | 21 | 59 | 78 |
| 10 | M | 9 | 13 | 0 | 80 | 89 |
| 11 | M | 16 | 6 | 21 | 59 | 75 |
| 12 | M | 20 | 2 | 22 | 58 | 78 |
| 13 | M | 21 | 1 | 7 | 73 | 94 |
| 14 | F | 21 | 1 | 29 | 51 | 72 |
| 15 | F | 22 | 0 | 38 | 42 | 64 |
| 16 | F | 16 | 6 | 14 | 66 | 82 |
| 17 | F | 18 | 4 | 29 | 51 | 69 |
| 18 | F | 11 | 11 | 14 | 66 | 77 |
| 19 | F | 15 | 7 | 16 | 64 | 79 |
| 20 | F | 18 | 4 | 21 | 59 | 77 |
| 21 | F | 7 | 15 | 3 | 77 | 84 |

| | | C/C | C/R | R/C | R/R | Total Correct |
|----------|-----|-----|-----|-----|-----|---------------|
| Mean - Males | | 18.4 | 3.6 | 20.3 | 59.7 | 78.1 |
| Mean - Females | | 16.0 | 6.0 | 20.5 | 59.5 | 75.5 |
| Overall Mean | | 17.5 | 4.5 | 20.4 | 59.6 | 77.1 |
| Overall Std. Dev. | | 4.42 | 4.42 | 13.6 | 13.6 | 11.3 |

In addition to providing raw data for the ROC analysis, Table 1 provides specific information on the performance of each individual. As the ROC analysis indicated, a number of people had high false alarm rates, in which they identified many genuine bills as counterfeit – and provided many comments about (real) printing flaws in the process. Others tended to accept all bills as geniune, while still others tended to be quite accurate – rejecting counterfeits and accepting genuinue bills. Both criterion and ability differences probably account for individual variability.

To turn to specific performance, examination of table 1 indicates that four people identified all 22 counterfeits as such, while five more identified 20 or 21 accurately. For genuine bills, one person identified all 82 bills correctly, while four others identified 73-77 bills (89-94 percent) accurately. At the other end of the continuum, one person identified only 7 counterfeits correctly, while another person identified only 18 genuine bills correctly. Thus, a wide range of ability and/or criterion differences were represented. It should be noted that chance performance alone would result in accurate identification of only 11 counterfeits and 41 genuine bills. No observer's performance was at this level. Clearly, however, the task of identifying counterfeit bills correctly is not so easy that everyone does it accurately.

The data were analyzed by sex of participant to determine if any differences existed. The eight females made more errors than the males, particularly with the counterfeits (mean of 16.0 vs 18.4 for C/C). This difference may have occurred because the females were primarily housewives, students, and secretaries, while the males were professionals and technicians, and possibly more familiar with larger denomination bills. The females tended to make slightly more errors with the $100's, as well. In fact, many of the observers expressed unfamiliarity with the larger denominations—which comprised much of the set of bills.

Table 1 can also be examined to obtain an idea of overall detectability of counterfeit bills. Thus, for C/C (correct identification of a counterfeit), the mean number correct out of 22 was 17.5 (with a standard deviation of 4.42), while for R/R decisions, the mean number correct was 59.6 (out of a total of 82). To compare the results for counterfeit and genuine bills, the data can be expressed in terms of percentage of the total number of each type of bill. Using this approach, it can be seen that the percentage of correct responses was similar for the two types, although it was slightly higher (78.4 percent) for counterfeit bills than for genuine bills (74.5 percent).

Thus, participants were slightly more accurate in identifying counterfeits as such, although even so, they made errors about 20 percent of the time.

3.1.2 Accuracy of Identifying Individual Bills

Table 2 presents data on the frequency of making errors for each counterfeit bill. The mean number of errors for all participants in detecting counterfeits accurately was 4.32, with a standard deviation of 2.9. No errors were made for one bill, 3217C, while only one error was made for two other bills, 1381A and 4051D. Two bills proved particularly difficult – 3691H with 12 errors or

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Table 2 - Frequency of Errors Made in Identifying
Counterfeit Bills

| Serial Number | Denomination | Errors Per Bill | Mean Errors Per Denomination | Total Errors Per Denomination |
|---|---|---|---|---|
| 0324E | $10 | 4 | 3.33 | 10 |
| 0436D | 10 | 3 | | |
| 3752F | 10 | 3 | | |
| 0759* | $20 | 5 | 2.67 | 16 |
| 3271C | 20 | 0 | | |
| 4051D | 20 | 1 | | |
| 6786A | 20 | 2 | | |
| 9111B | 20 | 2 | | |
| 9197C | 20 | 6 | | |
| 0395D | $50 | 6 | 6.00 | 36 |
| 1381A | 50 | 1 | | |
| 2236D | 50 | 2 | | |
| 3691H | 50 | 12 | | |
| 8194A | 50 | 5 | | |
| 9428A | 50 | 10 | | |
| 1292A | $100 | 5 | 4.71 | 33 |
| 3807A | 100 | 4 | | |
| 4275B | 100 | 7 | | |
| 4967A | 100 | 5 | | |
| 6554A | 100 | 5 | | |
| 7868A | 100 | 5 | | |
| 9235A | 100 | 2 | | |

Overall Mean Errors  = 4.32
Overall Total Errors = 95

incorrect identifications, and 9428A with 10 errors. Both these $50 bills were incorrectly identified as genuine by most of the observers.

Table 3 presents similar data for the genuine bills categorized by denomination and by wear category. The table presents the number of errors, or the number of times a genuine bill was termed counterfeit. The overall mean number of errors for the 80 genuine bills was 5.6, with a standard deviation of 2.75 and a range of 1 to 13.

The data are further discussed in terms of wear category and denomination. In terms of denomination, $100's were most likely to be termed counterfeit and $10's least likely, although there was a large effect of wear category. As table 3 indicates for $10's, the overall mean frequency of "counterfeits" detected was 4.6, with "good" $10's somewhat more likely to be termed "counterfeit". Table 3 indicates further that the mean frequency of terming a $20 as counterfeit was higher – 6.2. "Very bad" $20's were most likely to be seen as counterfeit, with a mean frequency of 9.33. "Bad" 20's on the other hand were much less likely to be termed counterfeit, with a mean of 3.57. The mean frequency of detecting counterfeits for $50's was 5.0, and for $100's was 6.55. For both denominations, the more worn the bill, the more frequently it was termed counterfeit. For both 50's and 100's as well, the "very bad" wear category was most likely to be termed counterfeit, with mean frequencies of 7.33 and 9.17, respectively.

Although counterfeit bills were not classified by wear category, effects related to denomination were observed. Table 2 indicates that counterfeit 10's and 20's were slightly more likely to be identified correctly as counterfeit than 50's or 100's. The number of errors tended to increase with denomination for counterfeits with mean errors of 3.34 for 10's; 3.2 for 20's; 5.14 for 50's; and 4.71 for 100's. Considering both counterfeit and genuine bills, error rates were most similar for $50's, and most different for $20's.

## 3.2  Features of Bills Noticed During the Pilot Study

### 3.2.1  Comments Made During the Examination

Examination of the comments that observers made while examining each bill can provide some clues about the features that people noticed about the different bills. Table 2 of the Appendix presents a listing of all comments made for counterfeits first and the genuine bills second. Review of this table indicates that the total number of comments was typically much larger for counterfeits than for real bills. In addition, many of the comments for genuine bills simply indicated that they were "OK".

Because of the volume of comments, comments were categorized so that some conclusions could be drawn about the features typically noticed. The following arbitrary categories were developed from the comments given by participants:

Table 3 - Frequency of Errors Made in Identifying Genuine Bills

| Serial Number | Denomination | Wear Category | Errors | Mean |
|---|---|---|---|---|
| 0768A | 10 | Good | 6 | 5.71 |
| 1278B | | | 7 | |
| 2679A | | | 7 | |
| 2885A | | | 6 | |
| 3494B | | | 6 | |
| 7333B | | | 1 | |
| 8361A | | | 7 | |
| 0100A | 10 | Bad | 4 | 3.86 |
| 4296E | | | 5 | |
| 5178B | | | 5 | |
| 5802A | | | 4 | |
| 6228C | | | 3 | |
| 7632E | | | 1 | |
| 9139B | | | 5 | |
| 1372A | 10 | Very Bad | 9 | 4.17 |
| 1695A | | | 3 | |
| 4317C | | | 2 | |
| 6854C | | | 3 | |
| 7949B | | | 4 | |
| 8686B | | | 4 | |

Overall Mean for $10's = 4.6          Total Errors = 92 ( 21.9%)

| Serial Number | Denomination | Wear Category | Errors | Mean |
|---|---|---|---|---|
| 1741D | $20 | Good | 8 | 6.14 |
| 1941D | | | 5 | |
| 1942D | | | 7 | |
| 3267C | | | 6 | |
| 6101B | | | 4 | |
| 7968D | | | 5 | |
| 8389F | | | 8 | |
| 0267A | $20 | Bad | 4 | 3.57 |
| 0716B | | | 5 | |
| 1227A | | | 2 | |
| 5654A | | | 4 | |
| 6092A | | | 1 | |
| 6919B | | | 5 | |
| 7293* | | | 4 | |
| 2998B | $20 | Very Bad | 6 | 9.33 |
| 3297A | | | 9 | |
| 4869* | | | 12 | |
| 6295E | | | 11 | |
| 7234E | | | 8 | |
| 8638C | | | 10 | |

Overall Mean for $20's = 6.2          Total Errors = 124 (29.5%)

## Table 3. Continued

| Serial Number | Denomination | Wear Category | Errors | Mean |
|---|---|---|---|---|
| 1855A | 50 | Good | 1 | 2.14 |
| 6381B | | | 1 | |
| 6592B | | | 2 | |
| 7144B | | | 4 | |
| 7741B | | | 2 | |
| 7921B | | | 2 | |
| 9882B | | | 3 | |
| 4967A | 50 | Bad | 2 | 5.86 |
| 5311A | | | 12 | |
| 7104B | | | 6 | |
| 8081A | | | 6 | |
| 8350A | | | 5 | |
| 8731A | | | 4 | |
| 9052A | | | 6 | |
| 1139B | 50 | Very Bad | 8 | 7.33 |
| 2507A | | | 11 | |
| 7701A | | | 6 | |
| 8776A | | | 10 | |
| 9265A | | | 3 | |
| 9695A | | | 6 | |

Overall Mean for $50's = 5.0    Total Errors = 100 (23.87)

| Serial Number | Denomination | Wear Category | Errors | Mean |
|---|---|---|---|---|
| 0934A | 100 | Good | 4 | 5.14 |
| 2119A | | | 3 | |
| 2136B | | | 6 | |
| 2860A | | | 6 | |
| 4108B | | | 6 | |
| 5318B | | | 6 | |
| 7405A | | | 5 | |
| 0046A | 100 | Bad | 7 | 5.71 |
| 0107A | | | 5 | |
| 2792A | | | 5 | |
| 2844A | | | 5 | |
| 3157A | | | 7 | |
| 5372A | | | 7 | |
| 5925A | | | 4 | |
| 1235A | 100 | Very Bad | 8 | 9.17 |
| 3251A | | | 8 | |
| 4723A | | | 8 | |
| 7183A | | | 10 | |
| 9159A | | | 8 | |
| 9602A | | | 13 | |

Overall Mean for $100's = 6.55    Total Errors = 131 (31.27.)

GENERAL

      Paper Wrong - PW
      Paper Feels Wrong - FW
      Bill Looks Funny - LF
      Creased/Folded Wrong - CR
      Unfamiliar With Design - UD
      Information, Design Wrong - IW

COLOR
      Too Yellow (usually paper) - TY
      Green Wrong - GW
      Color Wrong (either ink or paper) - CW
      Black Wrong (usually ink) - BW

CONTRAST
      Too Dark (Black Too Dark; White Too White) - TD
      Too Light (Too Grey) - TL

DETAIL
      Lacks Detail, Sharpness, Looks Like a Photocopy - LD
      Printing Defect, Ink Smeared or Spotted - D
      Problem With Portrait - PP

FADING
      Faded Wrong, Dirty - FD
      Wear Inconsistent With Age - WA

COUNTERFEIT CHARACTERISTICS
      Blunt Points on Seal - BPS
      No Threads - NT
      Borders Trimmed Wrong - IB

Because many people made more than one comment about some bills, the total number of comments is greater than the total number of participants. In addition, it was difficult to categorize some comments. Thus, "Looks like a xerox" was treated as lacking detail (LD), while "Looks washed out" was treated as lacking contrast or too light (TL). Comments relating to printing press quality, such as "looks blotchy" or "stray ink" were treated as a printing press defect problem (D), but it was sometimes difficult to separate these type of comments from those relating to lack of detail. Thus, the categorization must be treated as an approximation, and the comments, given in Appendix A, read in detail, to learn more fully what each person reported.

The comments in each category were totaled to provide an overall indication of the types of problems that were noticed about both counterfeit and genuine bills. Table 4 gives the total number of each type of comment for both counterfeit and genuine bills, as well as the frequency for each comment for each bill type.

The greatest number of comments about counterfeit bills were made for the following categories: Feels wrong (95); Color wrong (74); Portrait Problems seemed to refer either to appearance or feel, but not enough information was recorded to distinguish these categories. When specific information was given, it was categorized as either looks wrong (LF) or feels wrong (FW). Other comments that were noted frequently included too much or too little contrast (TD and TL, 41 and 33, respectively).

Examination of table 4 indicates large differences in the frequency with which particular comments were made between counterfeit and genuine bills. For counterfeit bills, comments about problems with the portrait, color, contrast, feel, and overall detail were made at least 4 times as much as for genuine bills. Comments about the paper being wrong, the bill looking funny, and wear being inconsistent with age also occurred with far greater frequency for the counterfeits. In contrast, the most frequently occurring comment for genuine bills was that the bill was "OK". The second most frequent was that it "felt wrong". In fact, comments about feel were common for both types of bills. People appeared to have strong notions about how real bills ought to feel. These notions were not always accurate, however, and sometimes seemed to confuse, rather than help participants. Nevertheless, comments about "feels wrong" occurred 4 times more frequently for counterfeit bills.

For genuine bills comments about "feels wrong" also occurred frequently. Only one category (other than "OK") received more comments for genuine bills. This category "irregular borders," referred to the amount of white under left on the edges of the bill. (Trim errors of this type were rare for counterfeit bills.) Table 4, thus, indicates numerous defects observed for counterfeit bills. These defects, relating primarily to the portrait, color, feel, and overall engraving quality appear to be the cues used by participants to distinguish counterfeit bills from genuine bills.


Table 5 presents the comment data categorized for each serial number. The most important thing to note is that fewer comments were typically made for genuine bills. For these bills, the range was 5 to 23, compared with 20 to 44 for counterfeits.

For counterfeit bills, bills receiving 38 or more comments included 0759*, 2236D, 1381A, 3271C, and 6786A. Bills receiving 21 or fewer comments included 3691H, 8194A, and 9428A. The counterfeit bills for which large numbers of comments were made generally received fewer identification errors; in other words, they were correctly identified as counterfeit.

Examination of table 5 indicates that different bills received different types of comments. Thus, 6 or more comments about contrast were made for 2236D (too dark), 4967A (too light), 6786A (too dark), while 4051D, 0759*, and 8194A were considered to feel wrong by 6 or more people. Frequent comments about wrong color were made for 1381A, 3271C, 4967A, and 4051D. Portrait problems were were particularly pronounced for 0324E and 3271C. Lack of detail was also a problem with 1381A, 2236D, 4051D, and 6554A.

Table 4.   Total Number of Comments in Each Category for Each Bill Type

| | FORGED | FREQ/BILL | GENUINE | FREQ/BILL |
|---|---|---|---|---|
| PORTRAIT PROBLEM | 92 | 4.18 | 86 | 1.11 |
| FADED, WORN | 17 | 0.77 | 46 | 0.58 |
| WEAR WRONG FOR AGE | 14 | 0.64 | 10 | 0.12 |
| BLUNT POINTS ON SEAL | 9 | 0.41 | 25 | 0.31 |
| NO THREADS | 24 | 1.09 | 60 | 0.75 |
| IRREGULAR BORDERS | 6 | 0.27 | 39 | 0.49 |
| OK | 8 | 0.36 | 132 | 1.65 |
| PAPER WRONG | 47 | 2.14 | 62 | 0.78 |
| FEELS WRONG | 95 | 4.32 | 119 | 1.49 |
| LOOKS FUNNY | 19 | 0.86 | 34 | 0.42 |
| CREASES WRONG | 9 | 0.41 | 27 | 0.34 |
| UNFAMILIAR WITH DESIGN | 6 | 0.27 | 17 | 0.21 |
| INFORMATION WRONG | 16 | 0.73 | 41 | 0.51 |
| TOO YELLOW | 23 | 1.05 | 14 | 0.18 |
| GREEN WRONG | 22 | 1.00 | 18 | 0.22 |
| COLOR WRONG | 74 | 3.36 | 47 | 0.59 |
| BLACKS WRONG | 11 | 0.50 | 15 | 0.19 |
| CONTRAST TOO DARK | 41 | 1.86 | 30 | 0.38 |
| CONTRAST TOO LIGHT | 33 | 1.50 | 23 | 0.29 |
| LACK OF DETAIL | 84 | 3.82 | 38 | 0.48 |
| PRINTING DEFECT | 19 | 0.86 | 63 | 0.79 |
| | | | | |
| TOTAL RESPONSES | 671 | | 924 | |
| | | | | |
| | | | | |
| TOTAL BILLS | 22 | | 80 | |

Table 5. Number of Comments in Each Category for Each Bill

COUNTERFEIT BILLS

| | 0324E | 0395D | 0436D | 0759* | 1292A | 1381A | 2236D | 3271C | 3691H | 3752F | 3807A | 4051D | 4275B | 4967A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PORTRAIT PROBLEM | 4 | 7 | 3 | 5 | 2 | 2 | 3 | 5 | 3 | 12 | 9 | 4 | 3 | 7 |
| FADED, WORN | 3 | 0 | 3 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEAR WRONG FOR AGE | 0 | 0 | 2 | 2 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 |
| BLUNT POINTS ON SEAL | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| NO THREADS | 0 | 1 | 2 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 2 | 0 | 0 | 0 |
| IRREGULAR BORDERS | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 |
| OK | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| PAPER WRONG | 4 | 2 | 4 | 0 | 2 | 3 | 2 | 4 | 0 | 3 | 3 | 0 | 0 | 3 |
| FEELS WRONG | 2 | 1 | 2 | 9 | 4 | 5 | 6 | 2 | 2 | 5 | 5 | 7 | 5 | 3 |
| LOOKS FUNNY | 0 | 2 | 1 | 3 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 |
| CREASES WRONG | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| UNFAMILIAR WITH DESIGN | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| INFORMATION WRONG | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| TOO YELLOW | 2 | 0 | 1 | 0 | 1 | 6 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 |
| GREEN WRONG | 0 | 0 | 1 | 1 | 0 | 3 | 3 | 1 | 1 | 0 | 1 | 1 | 1 | 2 |
| COLOR WRONG | 6 | 2 | 6 | 2 | 4 | 9 | 3 | 5 | 1 | 2 | 3 | 10 | 0 | 4 |
| BLACKS WRONG | 0 | 1 | 0 | 1 | 0 | 1 | 4 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| CONTRAST TOO DARK | 1 | 0 | 1 | 4 | 2 | 3 | 9 | 3 | 1 | 0 | 0 | 3 | 0 | 0 |
| CONTRAST TOO LIGHT | 1 | 4 | 0 | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 2 | 1 | 1 | 9 |
| LACK OF DETAIL | 7 | 2 | 3 | 2 | 5 | 6 | 6 | 7 | 3 | 4 | 2 | 7 | 5 | 1 |
| PRINTING DEFECT | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 0 | 0 |
| TOTAL RESPONSES | 31 | 26 | 34 | 40 | 29 | 44 | 43 | 39 | 20 | 32 | 30 | 37 | 20 | 35 |
| TOTAL ERRORS | 4 | 6 | 3 | 5 | 5 | 1 | 2 | 0 | 12 | 3 | 4 | 1 | 7 | 5 |

Table 5 - (Continued)

|  | COUNTERFEIT | | | | | | | | REAL | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 6554A | 6786A | 7868A | 8194A | 9111B | 9197C | 9235A | 9428A | 0046A | 0100A | 0107A | 0267A | 0716B |
| PORTRAIT PROBLEM | 6 | 3 | 3 | 4 | 3 | 3 | 5 | 2 | 0 | 1 | 0 | 2 | 1 |
| FADED, WORN | 2 | 0 | 0 | 0 | 0 | 1 | 3 | 2 | 0 | 0 | 0 | 0 | 0 |
| WEAR WRONG FOR AGE | 0 | 0 | 0 | 2 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| BLUNT POINTS ON SEAL | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| NO THREADS | 0 | 0 | 4 | 1 | 0 | 1 | 1 | 1 | 0 | 2 | 0 | 0 | 1 |
| IRREGULAR BORDERS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| OK | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 2 | 1 | 2 | 2 |
| PAPER WRONG | 2 | 4 | 1 | 2 | 2 | 2 | 4 | 2 | 4 | 0 | 1 | 1 | 0 |
| FEELS WRONG | 3 | 3 | 8 | 9 | 7 | 5 | 2 | 3 | 0 | 0 | 1 | 1 | 1 |
| LOOKS FUNNY | 2 | 1 | 1 | 0 | 3 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| CREASES WRONG | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| UNFAMILIAR WITH DESIGN | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| INFORMATION WRONG | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 3 | 0 | 1 | 0 | 0 |
| TOO YELLOW | 1 | 4 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GREEN WRONG | 0 | 1 | 3 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| COLOR WRONG | 4 | 4 | 1 | 0 | 4 | 5 | 1 | 2 | 0 | 1 | 0 | 0 | 1 |
| BLACKS WRONG | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| CONTRAST TOO DARK | 0 | 6 | 0 | 2 | 2 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| CONTRAST TOO LIGHT | 2 | 1 | 2 | 0 | 1 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| LACK OF DETAIL | 7 | 2 | 1 | 3 | 4 | 5 | 5 | 4 | 1 | 2 | 1 | 0 | 0 |
| PRINTING DEFECT | 0 | 6 | 1 | 1 | 0 | 1 | 1 | 2 | 1 | 0 | 0 | 2 | 2 |
| TOTAL RESPONSES | 29 | 36 | 30 | 26 | 31 | 34 | 32 | 22 | 14 | 8 | 8 | 9 | 9 |
| TOTAL ERRORS | 5 | 2 | 5 | 5 | 2 | 6 | 2 | 10 | 7 | 4 | 5 | 4 | 5 |

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Table 5 – (Continued)

| | 0768A | 0934A | 1139B | 1227A | 1235A | 1278B | 1372A | 1695A | 1741D | 1885A | 1941D | 1942D | 2119A | 2136B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PORTRAIT PROBLEM | 3 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 2 |
| FADED, WORN | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEAR WRONG FOR AGE | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BLUNT POINTS ON SEAL | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| NO THREADS | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| IRREGULAR BORDERS | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| OK | 4 | 2 | 2 | 2 | 1 | 2 | 0 | 3 | 4 | 4 | 0 | 1 | 2 | 0 |
| PAPER WRONG | 0 | 1 | 1 | 0 | 2 | 1 | 3 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| FEELS WRONG | 2 | 1 | 4 | 1 | 7 | 1 | 4 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| LOOKS FUNNY | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| CREASES WRONG | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| UNFAMILIAR WITH DESIGN | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 |
| INFORMATION WRONG | 2 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| TOO YELLOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GREEN WRONG | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| COLOR WRONG | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 |
| BLACKS WRONG | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| CONTRAST TOO DARK | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | 1 | 1 | 0 | 0 |
| CONTRAST TOO LIGHT | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 |
| LACK OF DETAIL | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 3 | 0 | 2 | 1 | 0 | 1 |
| PRINTING DEFECT | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 2 | 0 | 2 | 3 | 0 | 0 |
| TOTAL RESPONSES | 12 | 7 | 16 | 5 | 20 | 13 | 18 | 7 | 17 | 6 | 10 | 9 | 8 | 9 |
| TOTAL ERRORS | 6 | 4 | 8 | 2 | 8 | 7 | 9 | 3 | 8 | 1 | 5 | 7 | 3 | 6 |

Table 5 - (Continued)

|  | 2507A | 2679A | 2792A | 2844A | 2860A | 2885A | 2998B | 3157A | 3251A | 3267C | 3297A | 3494B | 4108B | 4296E |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PORTRAIT PROBLEM | 3 | 2 | 3 | 0 | 3 | 1 | 1 | 1 | 3 | 0 | 2 | 0 | 0 | 3 |
| FADED, WORN | 9 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 1 | 0 | 2 | 0 | 0 | 1 |
| WEAR WRONG FOR AGE | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| BLUNT POINTS ON SEAL | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 |
| NO THREADS | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 3 | 0 | 1 | 0 | 1 | 2 |
| IRREGULAR BORDERS | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 |
| OK | 0 | 2 | 0 | 2 | 2 | 1 | 1 | . | 0 | 3 | 1 | 3 | 2 | 1 |
| PAPER WRONG | 0 | 0 | 3 | 3 | 2 | 1 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| FEELS WRONG | 0 | 2 | 0 | 2 | 0 | 3 | 1 | 2 | 5 | 1 | 1 | 1 | 3 | 0 |
| LOOKS FUNNY | 1 | 2 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| CREASES WRONG | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| UNFAMILIAR WITH DESIGN | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| INFORMATION WRONG | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 0 | 0 | 1 | 1 | 1 |
| TOO YELLOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| GREEN WRONG | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 |
| COLOR WRONG | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 6 | 0 | 0 | 1 |
| BLACKS WRONG | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CONTRAST TOO DARK | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 2 | 1 | 0 |
| CONTRAST TOO LIGHT | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| LACK OF DETAIL | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| PRINTING DEFECT | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 4 | 0 | 2 | 1 | 0 |
| TOTAL RESPONSES | 18 | 16 | 11 | 11 | 14 | 12 | 13 | 11 | 17 | 14 | 18 | 11 | 13 | 15 |
| TOTAL ERRORS | 11 | 7 | 5 | 5 | 6 | 6 | 6 | 7 | 8 | 6 | 9 | 6 | 6 | 5 |

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Table 5 – (Continued)

| | 43317C | 4723A | 4869* | 5178B | 5311A | 5318B | 5372A | 5654A | 5802A | 5925A | 6092A | 6101B | 6228C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PORTRAIT PROBLEM | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 1 |
| FADED, WORN | 0 | 2 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEAR WRONG FOR AGE | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| BLUNT POINTS ON SEAL | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NO THREADS | 1 | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 2 | 1 | 1 | 0 | 0 |
| IRREGULAR BORDERS | 0 | 0 | 0 | 0 | 10 | 0 | 2 | 0 | 1 | 0 | 0 | 3 | 0 |
| OK | 3 | 0 | 0 | 1 | 0 | 3 | 0 | 2 | 0 | 2 | 2 | 1 | 4 |
| PAPER WRONG | 0 | 2 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| FEELS WRONG | 2 | 5 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 |
| LOOKS FUNNY | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| CREASES WRONG | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 0 | 0 | 0 |
| UNFAMILIAR WITH DESIGN | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| INFORMATION WRONG | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| TOO YELLOW | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GREEN WRONG | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| COLOR WRONG | 0 | 2 | 2 | 0 | 1 | 1 | 1 | 0 | 1 | 2 | 0 | 2 | 0 |
| BLACKS WRONG | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| CONTRAST TOO DARK | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| CONTRAST TOO LIGHT | 0 | 0 | 0 | 0 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| LACK OF DETAIL | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 |
| PRINTING DEFECT | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 4 | 2 |
| TOTAL RESPONSES | 10 | 19 | 21 | 9 | 20 | 14 | 10 | 9 | 11 | 14 | 5 | 17 | 7 |
| TOTAL ERRORS | 2 | 8 | 12 | 5 | 12 | 6 | 7 | 4 | 4 | 4 | 1 | 4 | 3 |

Table 5 – (Continued)

| | 6295E | 6381B | 6592B | 6854C | 6919B | 7104B | 7144B | 7183A | 7234E | 7293* | 7333B | 7405A | 7632E | 7701A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PORTRAIT PROBLEM | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| FADED, WORN | 2 | 0 | 0 | 1 | 0 | 2 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |
| WEAR WRONG FOR AGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| BLUNT POINTS ON SEAL | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| NO THREADS | 2 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 3 |
| IRREGULAR BORDERS | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| OK | 1 | 3 | 4 | 2 | 2 | 0 | 0 | 1 | 1 | 0 | 3 | 0 | 4 | 2 |
| PAPER WRONG | 0 | 0 | 1 | 0 | 0 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| FEELS WRONG | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 2 | 1 | 2 |
| LOOKS FUNNY | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 2 | 2 | 0 | 1 |
| CREASES WRONG | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| UNFAMILIAR WITH DESIGN | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| INFORMATION WRONG | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 1 | 0 |
| TOO YELLOW | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| GREEN WRONG | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| COLOR WRONG | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 0 | 0 |
| BLACKS WRONG | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| CONTRAST TOO DARK | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| CONTRAST TOO LIGHT | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| LACK OF DETAIL | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| PRINTING DEFECT | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 2 | 0 | 1 | 0 | 2 | 1 | 0 |
| TOTAL RESPONSES | 21 | 6 | 8 | 10 | 9 | 12 | 10 | 13 | 15 | 11 | 6 | 10 | 9 | 12 |
| TOTAL ERRORS | 11 | 1 | 2 | 3 | 5 | 4 | 4 | 10 | 8 | 4 | 1 | 5 | 1 | 6 |

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Table 5 – (Continued)

| | 7741B | 7921B | 7949B | 7968D | 8081A | 8350A | 8361A | 8389F | 8638C | 8686B | 8731A | 8776A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PORTRAIT PROBLEM | 0 | 1 | 1 | 2 | 0 | 0 | 1 | 3 | 1 | 2 | 0 | 2 |
| FADED, HORN | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 2 | 2 | 0 | 0 |
| WEAR WRONG FOR AGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| BLUNT POINTS ON SEAL | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| NO THREADS | 0 | 0 | 2 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 3 |
| IRREGULAR BORDERS | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| OK | 2 | 2 | 0 | 3 | 3 | 1 | 3 | 2 | 3 | 2 | 3 | 0 |
| PAPER WRONG | 1 | 0 | 2 | 0 | 0 | 1 | 1 | 0 | 3 | 1 | 1 | 5 |
| FEELS WRONG | 1 | 0 | 1 | 0 | 1 | 3 | 1 | 3 | 4 | 2 | 0 | 1 |
| LOOKS FUNNY | 2 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| CREASES WRONG | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| UNFAMILIAR WITH DESIGN | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| INFORMATION WRONG | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 |
| TOO YELLOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| GREEN WRONG | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| COLOR WRONG | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 2 |
| BLACKS WRONG | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CONTRAST TOO DARK | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 |
| CONTRAST TOO LIGHT | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| LACK OF DETAIL | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 1 |
| PRINTING DEFECT | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 0 |
| TOTAL RESPONSES | 8 | 6 | 7 | 10 | 14 | 10 | 12 | 16 | 26 | 12 | 8 | 17 |
| TOTAL ERRORS | 2 | 2 | 4 | 5 | 6 | 5 | 7 | 8 | 10 | 4 | 4 | 10 |

Table 5 – (Continued)

| | 9052A | 9139B | 9159A | 9265A | 9602A | 9695A | 9882B |
|---|---|---|---|---|---|---|---|
| PORTRAIT PROBLEM | 0 | 1 | 1 | 1 | 3 | 2 | 0 |
| FADED, WORN | 1 | 0 | 1 | 2 | 0 | 0 | 0 |
| WEAR WRONG FOR AGE | 0 | 1 | 0 | 0 | 2 | 0 | 0 |
| BLUNT POINTS ON SEAL | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| NO THREADS | 2 | 1 | 1 | 0 | 0 | 1 | 1 |
| IRREGULAR BORDERS | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| OK | 1 | 1 | 0 | 1 | 1 | 3 | 4 |
| PAPER WRONG | 0 | 0 | 4 | 1 | 1 | 2 | 1 |
| FEELS WRONG | 3 | 1 | 1 | 1 | 2 | 0 | 2 |
| LOOKS FUNNY | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| CREASES WRONG | 2 | 1 | 0 | 1 | 0 | 2 | 0 |
| UNFAMILIAR WITH DESIGN | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| INFORMATION WRONG | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| TOO YELLOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GREEN WRONG | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| COLOR WRONG | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| BLACKS WRONG | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| CONTRAST TOO DARK | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| CONTRAST TOO LIGHT | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| LACK OF DETAIL | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| PRINTING DEFECT | 0 | 0 | 0 | 0 | 6 | 0 | 0 |
| TOTAL RESPONSES | 11 | 10 | 13 | 9 | 18 | 13 | 11 |
| TOTAL ERRORS | 6 | 5 | 8 | 3 | 13 | 6 | 3 |

Two counterfeits (3691H and 9428A) had many errors, and relatively few comments. Yet, the 20-21 comments they received, while a low number for counterfeits, was a high number for genuine bills. This suggests that people noticed something about these 2 bills that they did not notice about most genuine bills.

For genuine bills, the number of comments varied from 5 to 26. Bills 1227A, 1885A, 6092A, 6381B, 7333B, and 7921B received only 5 or 6 comments, while bills 1235A, 4869*, 5311A, 8638C, and 6295E received 20 to 26. Large numbers of comments were typically made for the bills which received many errors (8-12 errors) unlike the counterfeit bills. Bills receiving few comments, on the other hand, had few errors (1 or 2).

For genuine bills, 2 bills (5311A and 8081A) received 6 or more comments about irregular borders. Other categories with 6 or more comments included: wrong color (2235A), faded (2507A), color wrong (3297A), too yellow (4869*), and printing defect (9602A). Unlike counterfeit bills, comments about problems with genuine bills did not cluster into categories. Furthermore, relatively few comments were made about portrait problems, poor contrast, or lack of detail for genuine bills, even though many such comments were were made for counterfeit bills.

At the end of the session, participants indicated the features that generally seemed to be most important in recognizing counterfeit bills. Table 3 of the appendix lists the features that each person considered to be most important for all bills. Each person also indicated if the noticeability of these features changed during the course of the study. Review of the comments in Table 3 of the appendix indicates that about 16 people thought that feel was an important cue in detecting counterfeits. Thirteen people indicated that color of paper, portrait quality, and sharpness of lines and detail were critical, while nine commented on shading, fine gradations, and contrast as important. Eight believed that problems of wear relative to age or intentional aging served as good cues. Only five people mentioned threads, with the majority of these comments relating to the difficulty of finding them in the set of bills used. Six people mentioned problems with the green seal or serial number (usually with the green color being wrong). Finally six people also discussed the quality of the border engraving as being an important cue.

While these comments are generally similar to the ones given for each bill, they do indicate that people used a set of rather systematic cues in trying to distinguish counterfeit bills from genuine. Without any training, other than that in general knowledge, they focused on cues related to the quality of the engraving, particularly in the portrait and in the border, as well as on fine gradations in shading and color. They also were aware of problems of intentional aging and looked for inconsistencies in wear relative to apparent age. The only misleading, but frequently cited cue was that of feel. As mentioned earlier, genuine bills were frequently noted as feeling wrong. Clearly, people's expectations about the feel of money were different from how money actually feels. This may, of course, be related to the worn characteristics of many of the bills, although many negative comments about the feel of new bills were also recorded. Nevertheless, the comment data in general indicate

that people noticed rather fine variations in bill quality, and used these as indicators of counterfeitedness.

Table 6 presents data on the amount of experience and training that participants reported having with counterfeit and genuine money. With the exception of summer employment, no person had spent much time as a cashier or store clerk. Most people reported being reluctant to carry large amounts of cash, and some unfamiliarity or even distrust of larger denominations. Only one or two people had any familiarity with the Secret Service publications on counterfeits, although a number of people had taken the Bureau of Engraving and Printing tour. It appears to be reasonable to conclude that participants in the pilot study were relatively inexperienced with cash handling in general, and with counterfeits in particular.

3.2.2  Portrait Data

During the debriefing following the conclusion of the pilot study, participants were questioned about whose portrait appeared on specific denominations ($1, 5, 10, 20, 50, and 100). At this point, they had viewed 31 $10's, 33 $20's, 35 $50's and 31 $100's (3 to 7 bills being counterfeit in any one denomination - but all bills being accurate in the use of the correct portrait for the denomination).

The data indicate that 85.7 percent of the participants correctly identified George Washington on the $1, 61.9 percent correctly identified Grant on the $50 and Franklin on the $100, and 52.4 percent identified Lincoln on the $5, Hamilton on the $10, and Jackson on the $20. It should be noted that participants did not view any $1's, $2's, or $5's in the study. Jefferson, whose potrait is actually on the $2, was mentioned as being on the $5, $10, or $20 by 2-3 participants. The percentage of "don't know" responses ranged from a high of 33 percent of the $5 to about 24 percent for the $10, $20, and $50 bill, to 10-15 percent for the $1 and the $100.

These data suggests that participants were very familiar with the $1 bill and its design characteristics. It is also possible that, since their comments indicated lesser familiarity with the $50's and 100's, they may have paid more attention to those bills, so that they had a slightly higher percentage of correct recognition for the portraits on those bills. It would be interesting to ask a random sample of 21 observers to identify the portraits for each denomination so that the problem of familiarity due to the experiment itself could be avoided.

3.3  Spectroradiometric Data

The possibilities for physical measurement of real and counterfeit currency present an embarassment of riches. Of particular interest are the spectral reflectances of paper and ink, as well as the sharpness of printed details. To compare a collection of notes, summary measures are desirable, particularly those which relate to human visual responses.

Table 6 - Reported Experience with Genuine and Counterfeit Money

| Participants | Experience | Look for Counterfeits | Training | Familiarity |
|---|---|---|---|---|
| 1 | No - uses credit cards | No | Quality; Threads | BEP Tour |
| 2 | Summer toll collector - rarely carries large bills | No - Looks at new bills | None | None |
| 3 | Some - uses cash | No | None | None |
| 4 | Little experience | No | Detail, Quality, Threads | BEP tour |
| 5 | Rarely carries large bills. Summer retail counter job. | No | TV Material | None |
| 6 | No - uses credit cards | Sometimes - encountered counterfeit US Bill in Mexico | Fibers; good quality | BEP tour |
| 7 | Carries Cash | Yes - frequently | Treasury reports and movies; | BEP Tour |
| 8 | Some cash | No | Phila. Mint | |
| 9 | 2 yrs. in U.S. - little cash | Never | None | None |
| 10 | Rarely carries cash - no large bills | No | None | None |
| 11 | Unfamiliar with large bills. Worked 4 months as cashier. Rarely carries much cash | No | None | None |

Table 6 - Reported Experience (cont.)

| | | | | |
|---|---|---|---|---|
| 12 | Cashier as teenager; rarely carries cash | No | Counterfeiters age bills | None |
| 13 | Sales experience as teenager; rarely carries large amounts of cash | Notices unusual colors - nothing regular | None<br>Ink rubs off - not sure if true for real bills or fake | None |
| 14 | Not much | No | Counterfeiters put in threads | None |
| 15 | Unfamiliar with big denominations | No | At an Exposition saw examples of counterfeit & real bills | |
| 16 | Carries cash | No | None | None |
| 17 | Unfamiliar with large denominations. Had home selling business | Recently has seen some funny-looking bills | None | None |
| 18 | Rarely anything larger than $20, uneasy with larger denomination | No | None | Tour of BEP |
| 19 | Rarely carries bills larger than $20 | No | None | Phila mint tour |
| 20 | Carries small amounts of cash | No | None | None |
| 21 | Cashier once - carries some cash | No | None | Once worked at Treasury but never saw counterfeit bills |

In the present study, spectral radiance was measured under a well-controlled source, at 3-8 spots on each note, and summary measures were computed from these spectral radiance functions, including the CIE chromaticity (x, y) and chromaticity in the CIE 1960 Uniform Color Space (u, v). The spectral radiance of a standard white surface was measured from time to time under identical conditions, so that spectral and luminous reflectance could be computed referred to the actual laboratory light source. While an ideal analysis would start with the spectral reflectance data and determine the chromaticities of papers and inks under a standard light such as an equal energy illuminant or Illuminant C, this was not done in the present case, because of equipment limitations. Data presented are all referred to the laboratory light, which is markedly yellower than Illuminant C or an equal energy light. This allows comparison between bills in this experiment, but not with data obtained using another source as the reference standard.

3.3.1 Measurement Data for Counterfeit Bills

The spectroradiometric data were taken for all counterfeit bils obtained from the Secret Service. Data for each of the measures taken per bill were tabulated for x,y coordinates and u,v coordinates as well as luminance. The u,v data were then graphed into a Uniform Color Space plot for each of the spots measured on the bills. Figure 3 presents a graph of the Uniform Color space showing the region of interest for currency measurements. All subsequent chromaticity measures are graphed in a portion of this space.

Table 4 of the Appendix presents CIE chromaticity data in both x,y and u,v coordinates as well as luminance values for the counterfeit bills actually used in the pilot study.

Figures 4 to 7 present the chromaticity data and reflectance data for all 108 counterfeit bills as a function of rapidprint number (an identifier used by the Secret Service). Table 4 of the appendix provides both rapidprint and serial number identification for each bill. These figures include the 22 counterfeits used in the pilot study. Figures 4 to 5 present data for the $10's and $100's while figures 6 to 7 present data for the $20's and $50's. The chromaticity data are graphed in the 1960 CIE Uniform Color Space (u, v) which allows ready comparison of perceived differences in color appearance measures. The reflectance data are presented as a function of Munsell Value, again to allow comparison of perceptual differences in reflectance.

Figure 4 presents chromaticity data for 3 spots measured on counterfeit $10 and $100 bills. These spots are: (4a) the white areas near the seal; (4b) the green Treasury seal itself; (4c) and the black letter for the Federal Reserve Bank. Examination of figure 4 shows that only the data for the green seal (4b) have much variability in chromaticity. Figures 4a and 4c, of course, represent black and white areas of the bill, where less variation in chromaticity might be expected.

Means and standard deviations were also calculated for five spots, including the front lathework and the portrait, and are presented in table 7. Table 7 presents data for $10's and $100's first and for $20's and $50's second. The
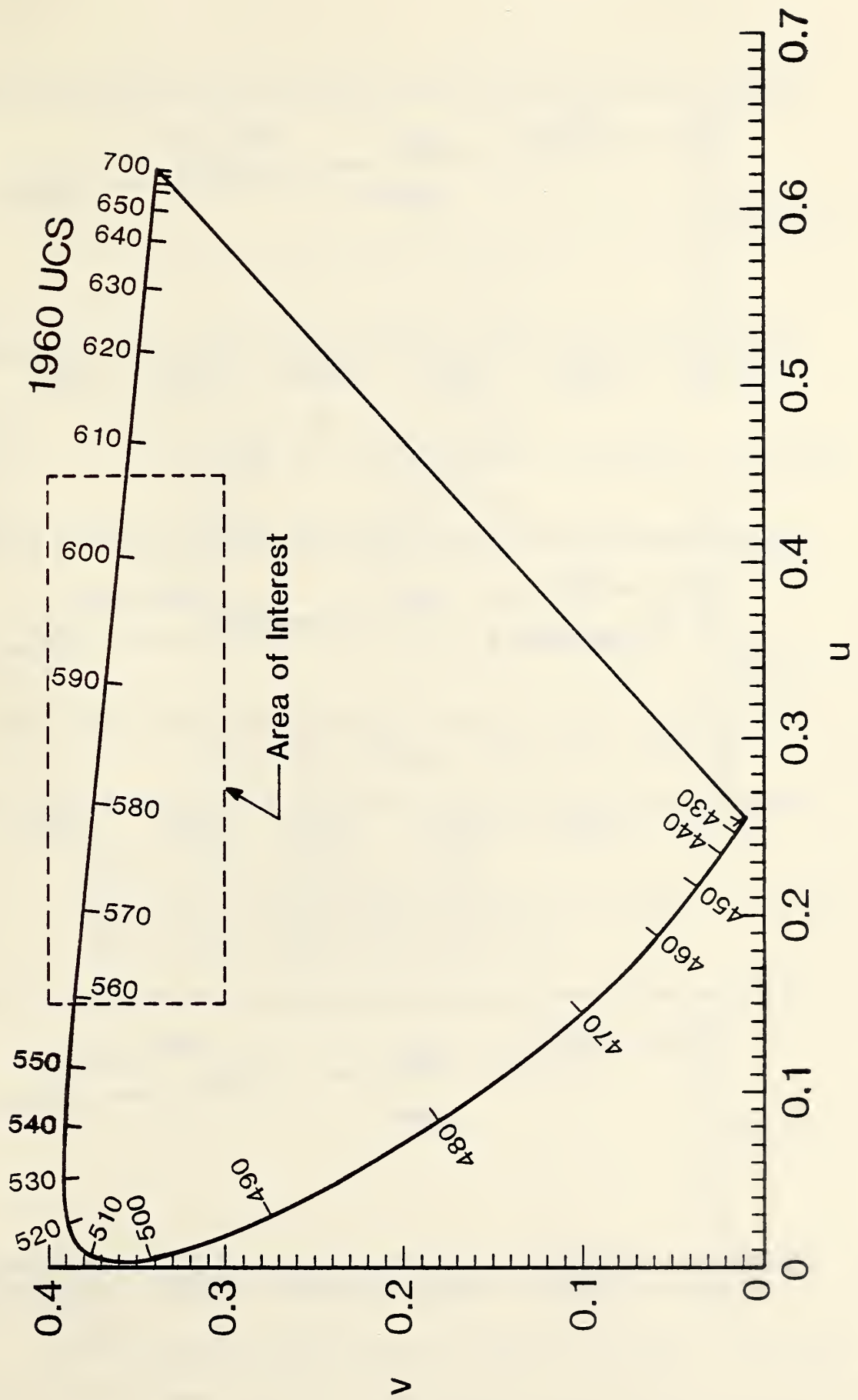
Figure 3. Uniform Color Space Showing Area of Interest for Currency Chromaticity Measurements.
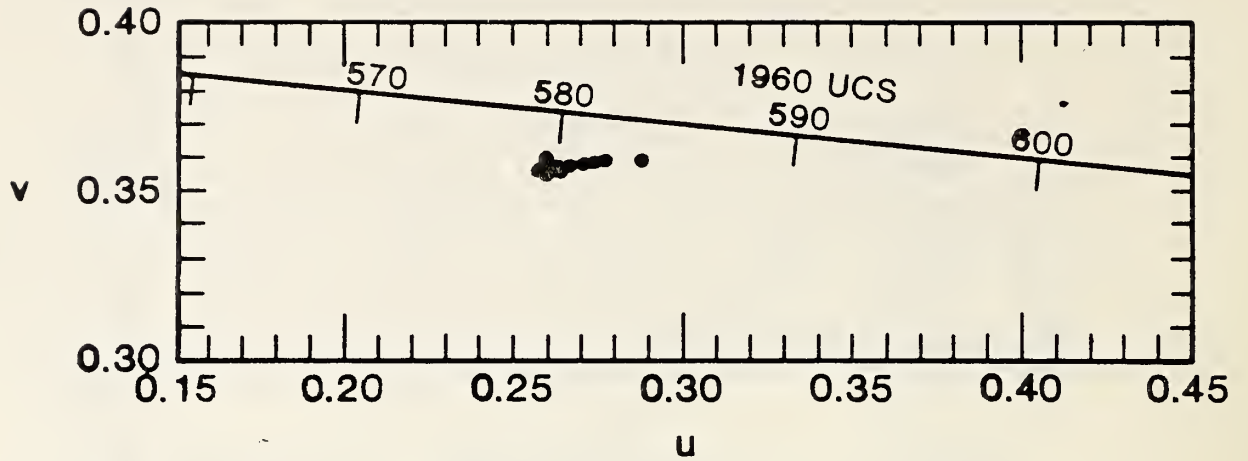
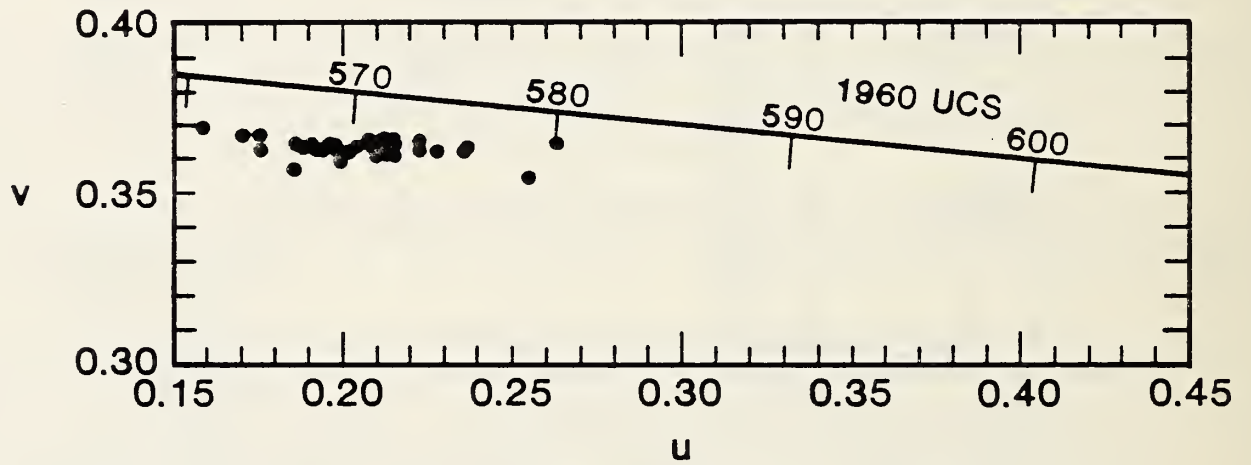Figure 4a.  Chromaticity data for white area near seal.
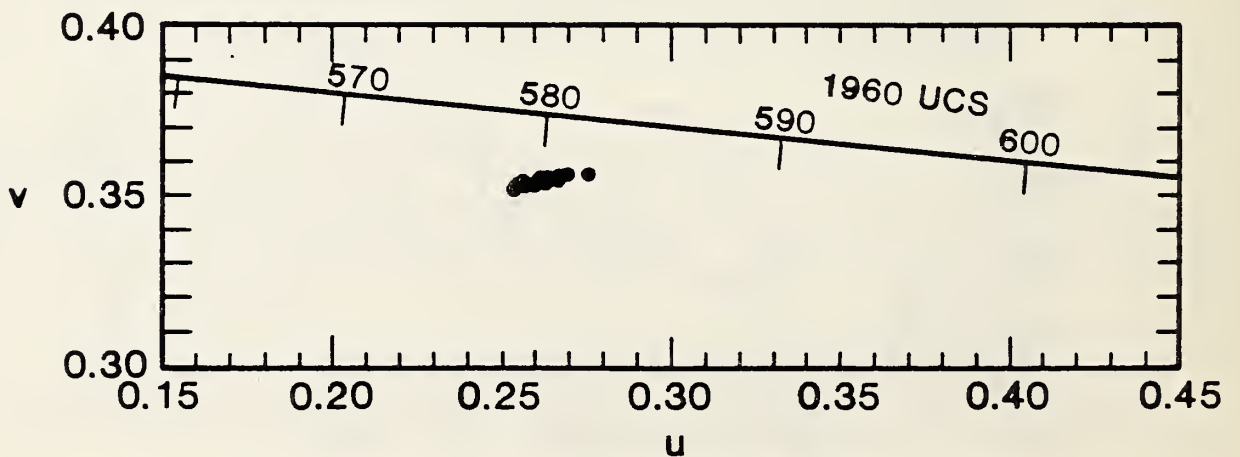


Figure 4b.  Chromaticity data for green seal.



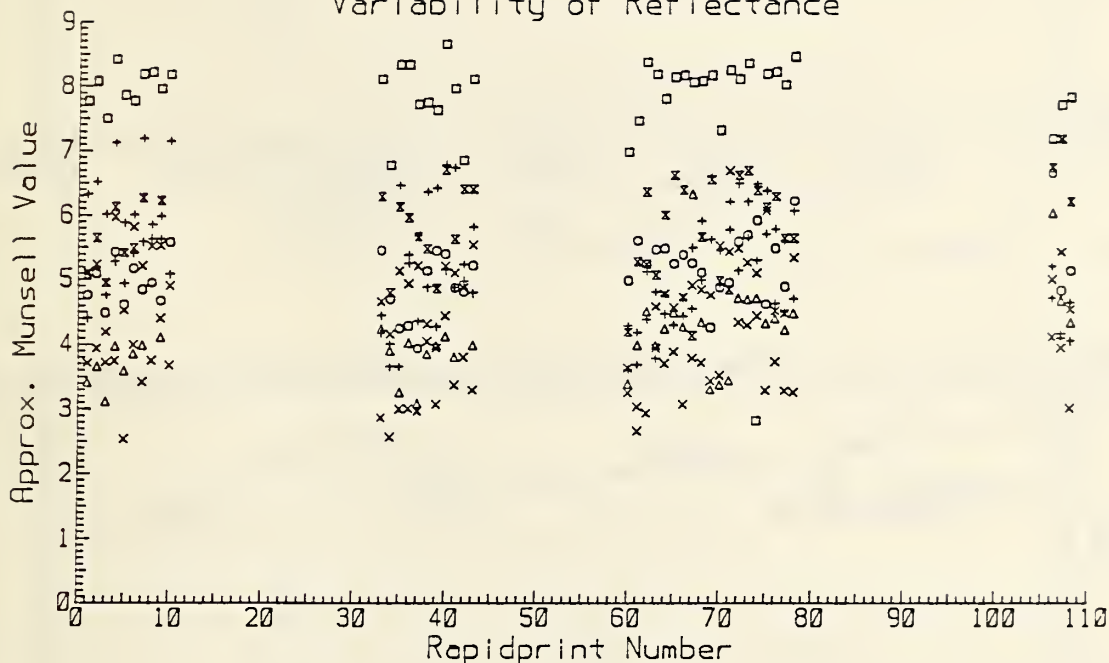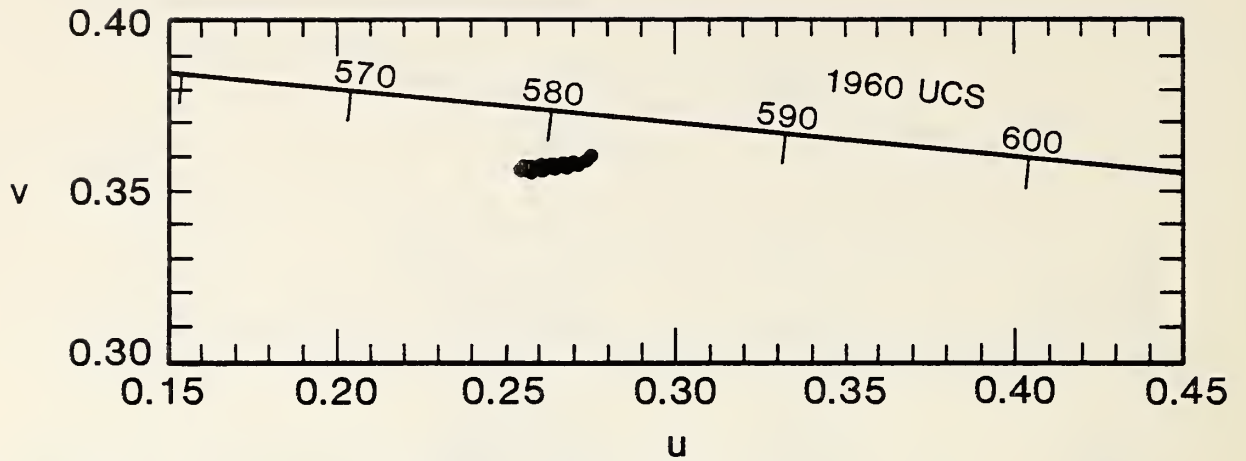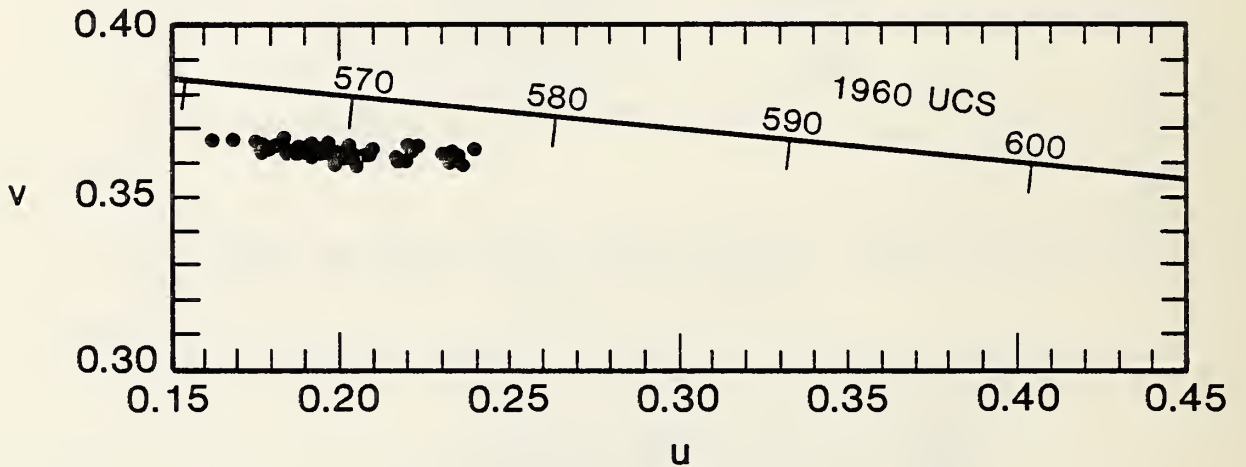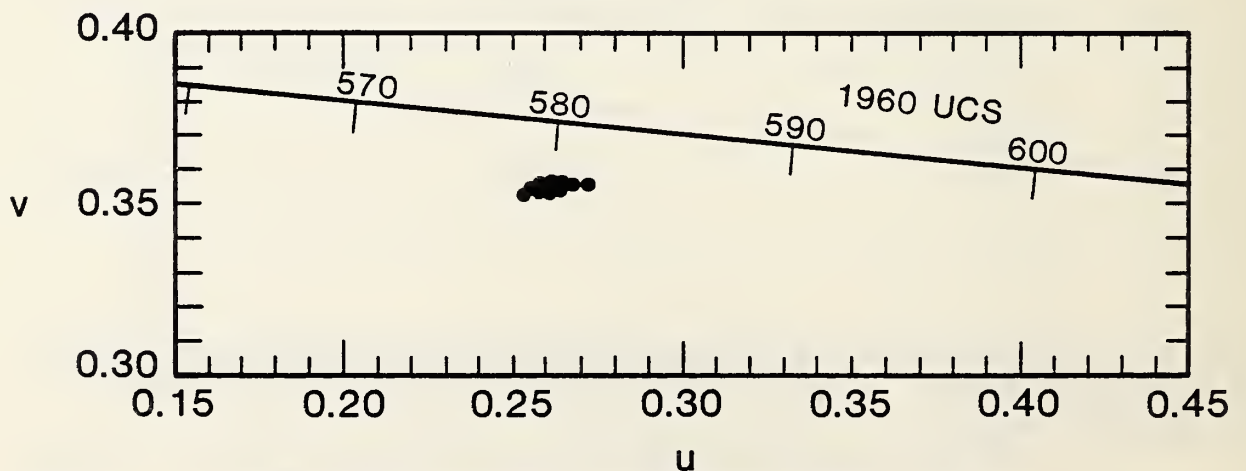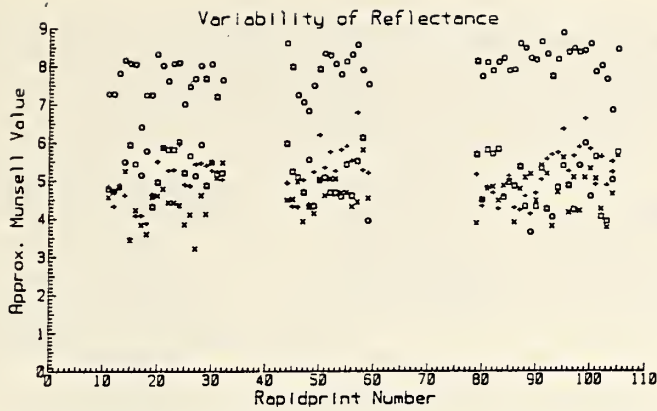Figure 4c.  Chromaticity data for black Federal Reserve letter.

Figure 4.  Chromaticity data for three areas for counterfeit $10's and $100's presented in 1960 Uniform Color Space.

Figure 5. Reflectance of measured spots on counterfeit $10's and $100,s presented as a function of rapidprint number and approximate Munsell Value.

Figure 6a.   Chromaticity data for white area.



Figure 6b.   Chromaticity data for green seal.



Figure 6c.   Chromaticity data for black Federal Reserve letter.

Figure 6.   Chromaticity data for three areas for counterfeit $20's and $50's presented in 1960 Uniform Color Space.

**Figure 7a.** Reflectance of lathework, green seal and white area.
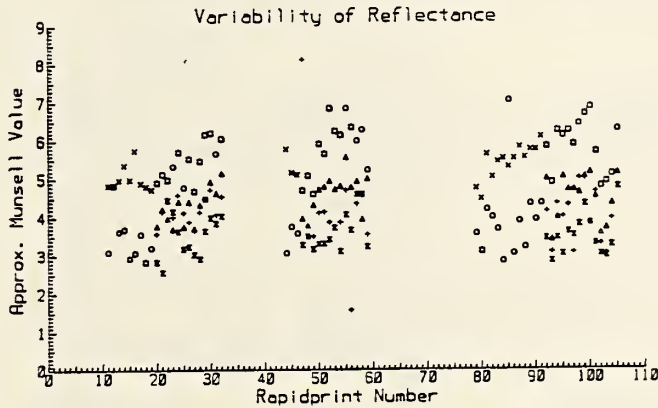


**Figure 7b.** Reflectance of portrait, black letter, and black and green areas of green seal.

**Figure 7.** Reflectance of measured spots on counterfeit $20's and $50's presented as a function of rapidprint number and approximate Munsell value.

Table 7. Mean Chromaticity Values in Uniform Color Space for Selected Spots on Counterfeit Bills

7a.  Values for Counterfeit $10's and $100's

| Location | Mean | | Standard Deviation |
|---|---|---|---|
| Front Lathe | u = | .260 | 0.004 |
| | v = | .355 | 0.010 |
| White | u = | .262 | 0.006 |
| | v = | .357 | 0.001 |
| Green | u = | .204 | 0.020 |
| | v = | .362 | 0.002 |
| Portrait | u = | 0.260 | 0.005 |
| | v = | 0.360 | 0.001 |
| Black Letter | u = | 0.261 | 0.004 |
| | v = | 0.355 | 0.001 |

7b.  Values for Counterfeit $20's and $50's

| Area | Mean | | Standard Deviation |
|---|---|---|---|
| .Front Lathework | u = | 0.258 | 0.004 |
| | v = | 0.355 | 0.009 |
| White Area | u = | 0.261 | 0.005 |
| | v = | 0.357 | 0.001 |
| Green | u = | 0.201 | 0.018 |
| | v = | 0.366 | 0.321 |
| Portrait − $50's | u = | 0.258 | 0.004 |
| | v = | 0.355 | 0.009 |
| Portrait − $20's | u = | 0.260 | 0.003 |
| | v = | 0.355 | 0.001 |
| Black Letter $50's | u = | 0.260 | 0.004 |
| | v = | 0.354 | 0.009 |
| Black Letter $20's | u = | 0.261 | 0.003 |
| | v = | 0.355 | 0.008 |

u,v coordinates are virtually the same for all spots, except for the green one where the u value has shifted further toward green. There is also much greater variability for this spot. It is possible that the observed variation in chromaticity of the "green seal" in the u direction may be largely a measuring artifact, while the seemingly smaller variation in the v dimension is probably significant. This variation suggests that counterfeiters permit a wider variation of their green in the blue-yellow dimension than does the Bureau of Engraving and Printing. The data suggest further that counterfeiters have reasonable control over the chromaticity of the black and white areas of the bills, both between and within bills.

Figure 5 presents the reflectance data for the counterfeits. Greater variability for these measures should be expected, particularly for the reflectances of the black and the white areas. The data are presented as approximate Munsell Value as a function of rapidprint number. Munsell Value is a measure of perceived brightness; a perfect white has a Value = 10. The variations in absolute reflectance relative to the 695 fL of the reference standard are too small to be readily meaningful. The Munsell Value Scale, however, translates these absolute variations into ones perceived by the eye, which is very sensitive to small variations in luminance. This scale thus is a better representation of the variability that is actually seen. Accounting for the eye's nonlinearity in this way gives the most meaningful measure of how much the bills vary in perceived reflectance. The data in figure 4 for $10's and $100's show considerable variation. The white spot (square) has the highest reflectance, while the black letter (x) has the least.

Means and standard deviations of Munsell Value were calculated and are presented in Table 8. Table 8 presents the reflectance data for $10's and $100's first (8a) and $20's and $50's second (8b). The white and black areas have the greatest variability in reflectance while the green has the least.

A similar pattern of data occurs for the $20's and $50's shown in figures 6 and 7. Means and standard deviations for the chromaticities $20's and $50's are presented in table 7b. As with the $10's and $100's, the green spot differs most in variability in chromaticity. The data are very similar to those for the $10's and $100's.

Figure 7 presents reflectance data for the counterfeit $20's and $50's. As in earlier measurements, the white area has the highest reflectance, while the black letter has the least.

Comparison of the data given in tables 7 and 8 indicate that the $20's and $50's differ somewhat from those for the $10's and $100's. The measurement of the overall mean Value is lower for the front lathework, while the mean for the $20's and for the $50's brackets that for $10's and $100's in the portrait area. For all denominations, measurements for a given spot typically have a range as much as a whole value unit, with the range being even larger for the black letter.

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Table 8. Mean Reflectance Data for Munsell Value for Selected Spots on Counterfeit Bills

8a. Values for Counterfeit $10's and $100's

| Location | Mean | Standard Deviation |
|----------|------|--------------------|
| Front Lathe | 4.94 | 0.599 |
| White | 7.82 | 0.886 |
| Green | 5.12 | 0.526 |
| Portrait | 4.83 | 0.634 |
| Black Letter | 3.62 | 0.700 |

8b. Values for Counterfeit $20's and $50's

| Location | Mean | Standard Deviation |
|----------|------|--------------------|
| Front Lathe | 4.62 | 0.553 |
| White Area | 7.93 | 0.502 |
| Green Seal | 5.11 | 0.620 |
| Portrait - $20's | 4.47 | 0.544 |
| Black Letter $20's | 3.54 | 0.534 |
| Portrait - $50's | 5.28 | 0.438 |
| Black Letter $50's | 3.70 | 0.874 |

These data appear consistent with participant comments about greens being wrong and blacks being greyed for the counterfeits. The differences are subtle, however, with the majority of the counterfeits having fairly low variability in chromaticity and reflectance.

## 3.3.2 Measurement Data for Genuine Bills

Spectroradiometric measurements were also made for a small set of genuine bills. Bills were selected for measurement on the basis of their performance in the pilot study. Thus, bills selected for measurement had received either a large number of errors or a very small number of errors. In addition, only the spots that had shown the greatest physical variability for the counterfeit bills were measured. These spots were: the white area near the portrait; the black area of the Federal Reserve letter; and the green of the Treasury Seal.

Figures 8 and 9 present both chromaticity data and reflectance data (in Munsell Value) for the three spots measured on genuine bills. Data for genuine bills are plotted as a function of new number - an arbitrary identifier. Table 5 of the appendix provides both serial number and new number identifiers, as well as the raw data for each bill. All denominations are plotted on each graph. In figure 9, reflectance is plotted first for all bills (8a) and then for each of the three wear conditions (figure 8).

Table 9 presents data on means and standard deviations for Munsell Value for genuine bills for all four denominations. Because it was thought that wear conditions might result in different Munsell Value, summary data are presented first for each condition and then for all conditions combined.

Data in Table 9 for genuine bills can be compared with those in Tables 10. The standard deviation for both u and v is smaller in all cases for the genuine bills. The mean chromaticity coordinates are very similar, except that mean values of u for the genuine green seal is shifted slightly to the left toward green, away from yellow. While this may indicate an intrusion of white into the measurements of the counterfeit bills, it may also indicate a genuine difference in the green seal between the two types of bills. This suggestion is reinforced by the great similarity between the chromaticity values for the other spots for both counterfeit and genuine bills.

The reflectance data for both types of bills can also be compared using Tables 8 and 9. This comparison indicates that for the white area, the mean reflectance Value for all counterfeit bills is lower than the mean Value for "good" genuine bills, and is even slightly lower than the mean Value for "bad" genuine bills. In addition, the standard deviation is higher particularly for counterfeit $10's and $100's. For the black area, the mean Value for the genuine bills is lower for all mean conditions (2.95 vs about 3.6) and much lower for "good" genuine bills. Again, the variability is lower for genuine bills.

For the green seal, the reflectance data for the genuine bills are also lower, indicating a more saturated green than on the counterfeit bills. The counterfeit Treasury seal is lighter than that for even the least worn genuine bill. Again the variability is greater for counterfeit bills.
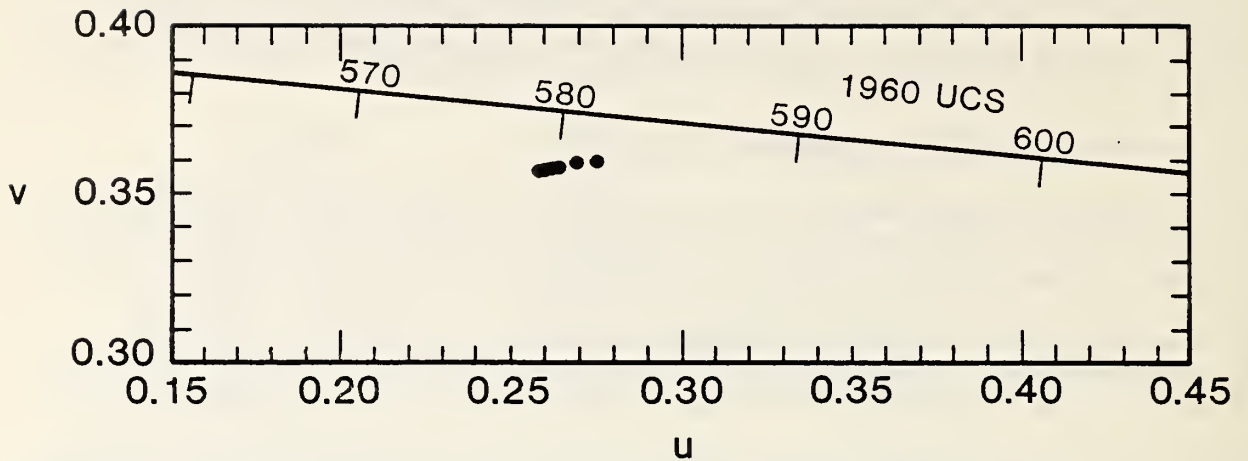
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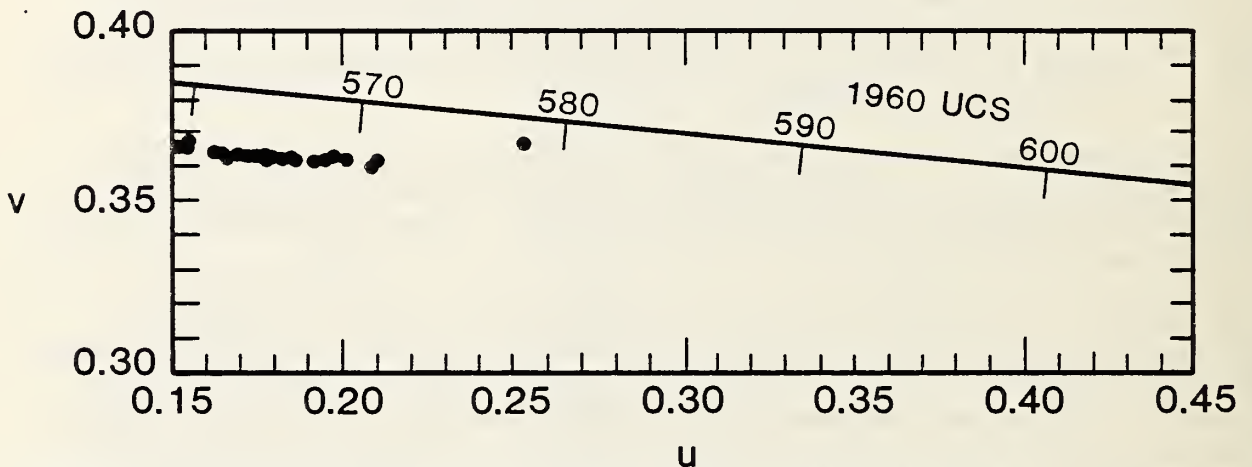Figure 8a.   Chromaticity data for white area of genuine bills.



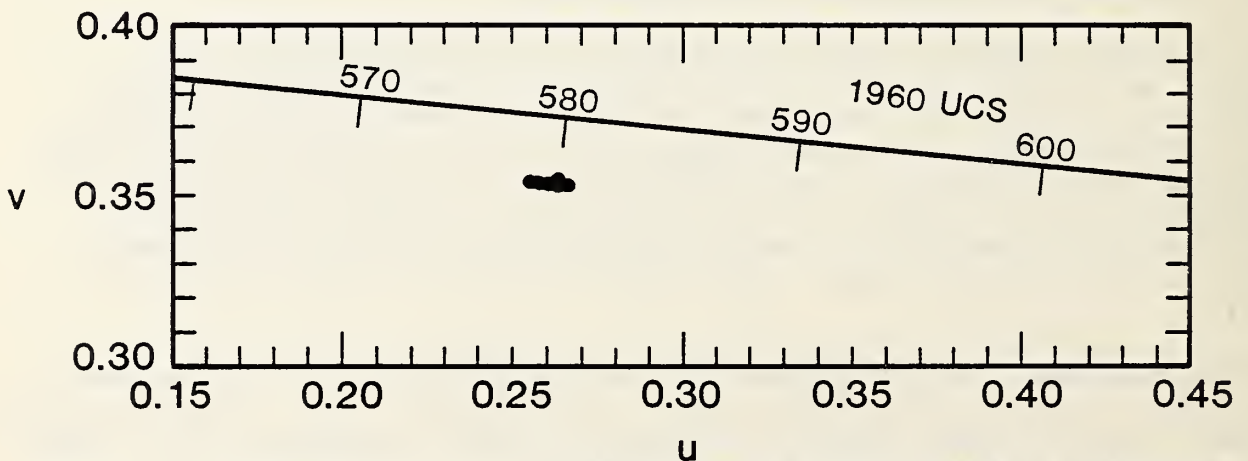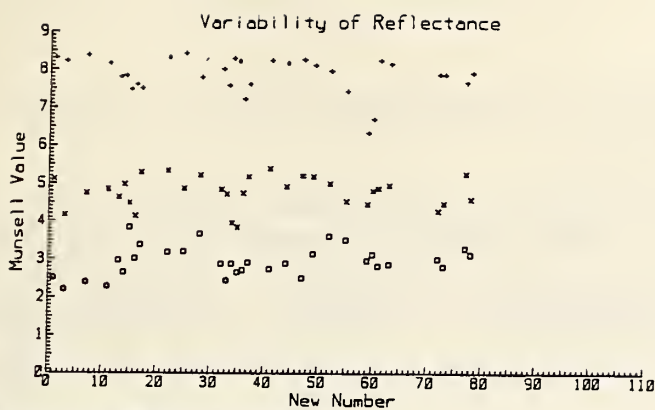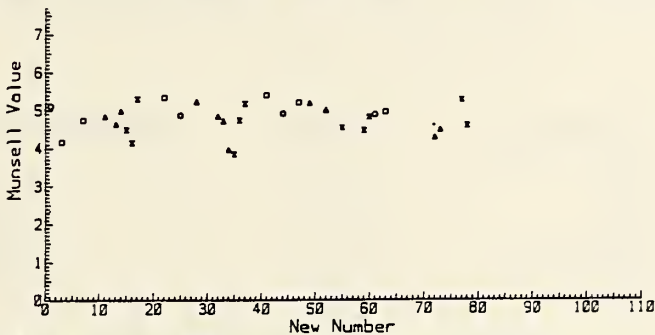Figure 8b.   Chromaticity data for green seal of genuine bills.



Figure 8c.   Chromaticity data for black Federal Reserve letter on genuine bills.

Figure 8.   Chromaticity data for three areas of genuine $10's, $20's, $50's, and $100's presented in 1960 Uniform Color Space.

Figure 9 a.   Reflectance of white area, green seal and black letter for genuine bills for all wear conditions combined.



Figure 9 b.   Reflectance of green seal for each wear condition.
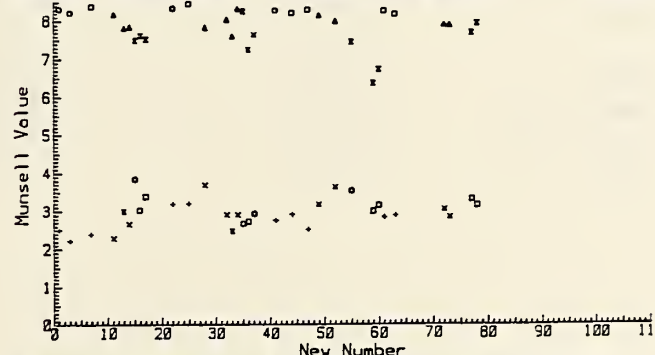


Figure 9 c.   Reflectance of white area and of black letter for each wear condition.

Figure 9.   Reflectance of measured spots on genuine bills presented as a function of New Number and Munsell Value.

Table 9. Chromaticity and Reflectance Data for a Selected Set of Genuine Bills

9a. Chromaticity Data

| Area | Coordinate | Mean | Standard Deviation |
|---|---|---|---|
| Treasury Seal - Green | u | 0.179 | 0.020 |
| | v | 0.364 | 0.002 |
| White Area | u | 0.260 | 0.004 |
| | v | 0.357 | 0.001 |
| Black Letter | u | 0.258 | 0.003 |
| | v | 0.354 | 0.001 |

9b. Munsell Value

| Area | Coordinate | Mean | Standard Deviation |
|---|---|---|---|
| White Area | Good | 8.29 | 0.087 |
| | Bad | 7.95 | 0.201 |
| | Very Bad | 7.44 | 0.526 |
| | All | 7.88 | 0.478 |
| Black Letter | Good | 2.74 | 0.330 |
| | Bad | 2.95 | 0.425 |
| | Very Bad | 3.15 | 0.347 |
| | All | 2.95 | 0.397 |
| Green Seal | Good | 4.96 | 0.353 |
| | Bad | 4.74 | 0.386 |
| | Very Bad | 4.67 | 0.457 |
| | All | 4.79 | 0.408 |

Counterfeit bills that had many comments about "wrong color" included: 0436D, 1381A, 3271C, and 4051D. These bills had higher "u" values for the green seal than the mean for the genuine bills (e.g., 0.222, 0.239, 0.219, and 0.232, compared with 0.179). They also had higher mean reflectance in the black area (3.62, 3.54, 3.70 vs. 2.95). The physical measures thus indicate real, observable differences in chromaticity and reflectance.

The difference in reflectance Value between genuine and counterfeit bills suggest that either counterfeit quality control is particularly poor for reflectance or that counterfeiters have deliberately aged their bills. Certainly, anecdotal evidence suggests that this occurs frequently. Even in the latter case, there are noticeable differences between counterfeit and genuine bills for the black and green areas. These differences mean that the blacks and greens are often darker on genuine bills, even worn genuine bills.

4. Conclusions

4.1 Discussion of Pilot Study Data

The major result in the pilot study is that, without any specialized training, participants were able to identify accurately the majority of the counterfeit bills presented. Yet, few participants were able to identify all bills accurately. Only four people identified all the counterfeits, while only one identified all the genuine bills. No person successfully identified all bills correctly. Overall accuracy was about 79 percent for counterfeit bills and about 74 percent for genuine bills.

Had participants been forced to make their decisions faster, in 1 second or less, as is common during an actual currency transaction, it is likely that they would have made many more errors for the counterfeits. To allow participants time to notice features in the bills, they were allowed to scan the front of the bill completely. In an actual currency transaction, which occurs much more rapidly, people may realistically only look at the denomination counter at one edge of the bill. They may not even expose the entire bill to view. As a result, the present experimental procedure was not realistic, nor was it intended to be a simulation of an actual cash transaction. Rather, it was intended to determine if untrained people were capable of discriminating counterfeits from genuine currency and to elicit information about which features of the bills were noticed.

The design of the study was such as to predispose people to find "counterfeits" in the stacks of money. The instructions specifically asked people to look for counterfeits rather than genuine bills, in the hopes that this would maximize the number detected and provide more information about the cues used for this discrimination. The result was that at least one person identified more than 60 percent of the genuine bills as counterfeit (while identifying all the counterfeits correctly). Yet, despite a predisposition to find "counterfeits", only four people correctly identified all 22 counterfeit bills. (All participants were adults, accustomed to at least a moderate level of currency handling, with all but two being salaried employees.)

The inescapable conclusion is that the set of counterfeit bills contained some very good counterfeits which did not differ a great deal from the genuine bills. The other conclusion is that it is somewhat difficult to discriminate counterfeits even when sufficient time is allowed.

Nevertheless, analysis of the comment data indicates that even when counterfeit bills were not identified correctly, people noticed different features of these bills. In addition, they made many more comments about counterfeit bills. Thus, even the two counterfeit bills that were identified as genuine received a large number of comments compared with actual genuine bills. This suggests that people noticed something about counterfeits that they did not notice about good bills. Similarly, Stillitz found that his observers had longer reaction times to forged notes, even when they were identified as genuine. Detailed analysis of the comment data indicates which features of counterfeit bills were noticed. The data strongly suggest that people noticed variations in

color, contrast, portrait realism, and overall engraving quality. For genuine bills, on the other hand, they noticed printing flaws such as ink spots and irregularly placed borders.

The data on portrait identification, while a bit surprising, can be interpreted to support the idea that engraving qualty is an important feature of genuine currency. Although participants accurately remembered only George Washington on the $1 bill, they commented frequently on the lifelike quality of the face and the way in which it stood out (or did not stand out) from its background for all denominations. These data suggest that although people may not be particularly aware of whose portrait is on which bill, their attention appears to be caught by the quality of the portrait. Whether a portrait was sharp, detailed, and lifelike seemed to be more important than whose portrait it was.

In large measure, the comment data paralleled the physical data. Where observers commented on irregular borders, for example, they were reporting an existing physical problem. When they noted that the ink color was wrong, the chromaticity data for the green seal frequently differed, along with the reflectance data for the white and black areas. Thus, the physical measures indicated observable differences in color and lightness, which participants often mentioned.

The comments indicated relatively little reliance on known security devices such as the red and blue threads or the points on the seal. Even though the Secret Service (1983) considers these as good indicators of counterfeit bills, only one observer in the pilot study indicated use of these as an indicator. The other observers stated that they looked for threads, and when they could not find them in several bills, they abandoned them as a good cue. The comments made during the debriefing indicated that people had a great deal of trouble finding the threads, particularly in worn bills. In fact, participants commented about the worn condition of many of the bills, saying that it was more diffi-cult to detect counterfeits among worn bills. They noted further that many of the counterfeits appeared intentionally aged, and that often this apparent wear was inconsistent with the age of the bill.

Participants also mentioned several bill characteristics that were not as reliable indicators of counterfeiting. These included "feel", irregular borders, and ink heaviness or blotches. The second two are related more to print quality control than to errors made by counterfeiters. (With very few exceptions, they positioned the engraving properly on the paper, and did not leave stray ink markings.) The comments related to feel, however, seem to indicate some real misconceptions about how money ought to feel, as well as some possible real variability within the set of genuine bills. For example, with new bills, people often commented that they feel "too thick" or "too thin". This last comment seemed to occur frequently for $100's. Other comments related more to badly worn bills and included comments related to "creasing", "bending", "feels like it would tear easily - real money shouldn't tear", and "feels papery". These comments seemed to be made about all bills, regardless of classification. Wear seems to create problems with accurate feel and appearance which make it more difficult to identify counterfeits, and which may increase willingness to tolerate deviations from good, high quality notes.

The data suggest that observers relied heavily on the engraving quality of the bills. Their comments about counterfeits related primarily to deficiencies in the quality of details, including both the portrait and the border, as well as to lack of fidelity in both color and contrast. These features functioned generally as reliable indicators of forgeries. As Andersen (1978) pointed out, high quality engraving continues to be a useful counterfeit deterrent. The intaglio process allows very fine variations in detail, color, and feel that are not yet achievable by other printing processes, but that are detectable by human observers. Participants in the pilot study clearly expected high quality engraving, and frequently rejected bills that they felt were poorly printed, with comments about how the government should do a better job.

4.2 Recommendations and Conclusions

The data from the pilot study and from Stillitz' studies provide some insight into the problem of counterfeit deterrence. These studies suggest a number of areas in which further research might be done to increase the discriminability of genuine bills. One of the most important is that of determining how to increase the attention-getting value, or conspicuity, of the engraving quality of the bill, particularly the portrait.

One of the Stillitz' ideas was to use the portrait as the sole denomination indicator. His idea was not followed up for British currency because of a desire to use the Queen's portrait on all notes. His idea is, however, already partially in use for U.S. currency where a different portrait is used on each bill. However, its effectiveness is diminished by the presence of counters at the edge of the bill.

Since the size of U.S. currency is currently constant and the bills are all the same color (as Stillitz recommended), the effect of varying the placement (and number) of the numerals relative to the portrait should be assessed. A study should evaluate the effectiveness of locating two numerals centrally, on each side of the portrait so that the user is forced to look at the portrait when trying to determine the bill's denomination. At the moment, it is too easy to determine denomination just by looking at a small fraction of the edges of the bill. (Counterfeiters take advantage of this tendency by "raising" the bill – pasting numerals from higher denominations on to notes of lower denomination.) The rest of the bill, including the all-important portrait can remain obscured, so that the security value of the engraving quality is lost. A research project should be designed in which the position of the numerals on the bill and the security engraving is manipulated, and reaction time, comprehension, and salience are assessed.

At the same time, the effects of greater variation in portrait appearance between bills should be assessed. Currently, all bills contain portraits of historical figures. Comments by the participants in the pilot study indicated that they were familiar with the appearance of Washington, Jefferson, Franklin, and Lincoln, but less so with Grant, Jackson, and Hamilton. The comments and portrait identification data suggest that some of the portraits do not have

the immediate recognition that the Queen has on British notes. The effects of varying historical period and using different styles of portraits (as with current U.S. coinage) should be determined, to assess the effects of familiarity with the portrait on forgery recognition. Another important area for further research is that of color. People are capable of very fine color discrimination and accurate color matches, while copying machines typically are not as accurate in reproducing these colors. Numerous comments in the pilot study related to yellowness, both of the paper itself and the green seal and serial numbers. People clearly noticed small color variations. Since Stillitz suggested that varying color between denominations is not a good idea, one might increase the number of colors slightly on all bills. The same set of colors should be used on each denomination. This would allow one to take advantage of the difficulties in reproducing similar colors, yet avoid the problem of characterizing denomination by color. It would also take advantage of the human visual system's ability to make fine color discriminations. Another set of studies could assess the effectiveness of varying color, or colors, for the set of bills under a variety of light sources and light levels. In addition, the effectiveness of specialized light sources for detecting a particular color used as a security device should be assessed, as should variation of security devices themselves.

Printing depth and paper quality is another area in which additional research is needed. Feel of the bill was a major criterion used by participants in the pilot study, along with color, line quality, and overall appearance in detecting counterfeits. For example, participants often commented that bills felt wrong for the age they appeared to be, or that bills were too limp or too thin. Stillitz also found feel to be a reliable sense for discriminating between genuine and forged notes. He determined as well, that people could reliably detect small differences in printing depth. Touch, along with color, is a sensory dimension in which people are capable of making small and accurate discriminations. As a result, the feasibility should be assessed of altering the feel of currency by increasing printing depth. Genuine notes would then be more discriminable in feel from photocopied forgeries. However, this change would require greater control over the wear of bills in circulation.

Finally the effects of increasing public awareness of counterfeits need to be assessed. Data from the pilot study indicate that when people are sensitized to the possible presence of counterfeits in a stack of bills, they find them, even when the bills are not actually forged. Stillitz also found that British observers would reliably find forgeries in a stack of genuine notes. These "forgeries" often contained real printing flaws that slipped past the quality control in note production. Yet, on the other hand, data from the pilot study indicate that not all people can find all counterfeit bills in a stack of money. Furthermore, Stillitz found several situations in which people did not even count their money, much less find the forgeries in it. As a result, people concerned with currency must be aware that, when sensitized to the possible presence of counterfeits, people become very aware of real printing flaws, and will find "counterfeits". They will also take more time to examine their money and decrease speed of currency transactions. This problem must be balanced against current casualness in money handling, in which money is assumed to be

genuine, and so failures in quality control are not identified. The problem is further exacerbated by worn currency in which some of the features of quality engraving are blurred as the bill ages. It is relatively easy to separate a new, genuine bill from an aged counterfeit. Yet, there are enough worn bills in circulation that it becomes worthwhile for counterfeiters to deliberately age their bills to camouflage them.

The present pilot study has suggested that while people can recognize counterfeit U.S. dollars, they do not do so with total accuracy, even in a situation designed to maximize detection of counterfeits. Research by Stillitz and other researchers (DeValois and DeValois, 1980), has pointed out that people are capable of very fine color, line quality, and tactile discriminations. Both the pilot study and Stillitz' research have demonstrated that people are sensitive to and will notice bill qualities resulting from good engraving and careful printing. These capabilities should be researched further to aid in developing effective counterfeit deterrents. Stillitz has emphasized, however, the need to increase the amount of time spent in inspecting the bill during normal currency transactions so that counterfeit deterrents and engraving quality are noticed. The present study reinforces this assertion, while recognizing that the costs of slowing down currency transactions must also be assessed.

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APPENDIX

Table 1. Instructions to Participants in Counterfeit Pilot Study

We are interested in how people detect counterfeit money. The U.S. Treasury carefully designed bills to be difficult to counterfeit, but a large number of fake bills are passed each year.

We want to determine what people actually notice when they examine paper money, so you will be asked to look at some real and some counterfeit money and tell use what you observe about these bills. We are interested in the ability to identify counterfeit bills and want to know what bills you think are counterfeit and what features of these bills you notice. Although this is not a real money-handling situation, plese imagine yourself having received these bills in a cash transaction. We will limit viewing time accordingly.

We will give you 3 stacks of bills with about 30 bills in each stack. Each stack may contain all types of bills. We will give you three stacks of bills consisting of ten, twenty, fifty, and one-hundred dollar bills in different stages of wear. These bills represent a mix of real and counterfeit money.

We want you to examine only the front of each bill and decide if it is real or counterfeit. Please examine it against the background of the table. When you have finished, please hand the bill to the experimenter, and say whether it is real or counterfeit. Please give the reasons your decision, telling us what you noticed about the bill. We would like you to go through one stack at a time, and then take a brief rest. We will give you about ten seconds to examine each bill and tell us about it. We will be writing down your impressions about each bill.

Describe what you noticed when examining the bill, and how you decided. When you finish, you will be given the next stack of bills.

As you go through the bills, please keep the following questions in mind. We will be discussing these at the end of the experiment.

Were any features especially important in making your judgement?

If so, what were they?

Were they different for different bills? If so, in what way?

At the end of the study, we would like you to indicate which features you found most important about those bills you identified as counterfeit. If you can, please define the features that you used. Start with the most important characteristics of the bills. (The experimenter has recorded the features that you mentioned, and can tell you them.)

How noticeable were those features? Easy to detect? Hard to detect? Please use a scale of 1 to 5 with 5 indicating the most difficult to detect.

Table 1 - (Continued)

Did you follow a particular procedure (pattern) for all bills?  Did you change
cues as you went along?  Did you notice any general features about the bills?
Did you find it easier to detect counterfeit as you went along?  If so, why?

General Comments.

How you had much experience handling cash, in a previous job, for example?

Ever see a counterfeit bill?

Do you examine paper money to see if it is counterfeit?

Were you trained to check?  How?

In the task, did you follow any previous training, or did you make up your
own procedure?  Which was more useful?

Have you read anything put out by the Treasury (or others) on how to
detect counterfeits?

Do you have any questions or comments?

Thank you very much for your participation.

APPENDIX

TABLE 2.   COMMENTS FOR EACH SERIAL NUMBER

COUNTERFEIT BILLS

0324E

Paper quality
Engraving not clear
Xerox looking
Ink looks wrong
Printing looks wrong
Very yellow
Wrong color all over
Uneven fading
Contrast on green seal
Portrait strange
Paper funny
Gold areas (where tape had been) look fake
Contrast too weak (dark not dark enough)
Poor quality printing
Portrait, lathework all bad
Black and green also bad
Stamped on too dark, not legible
Bad paper
Almost a xerox, poor graphics
Long creases, real poor
Don't like his face
Not clearly printed - not precise
Lack of detail on border, too much shadow under lettering
Too yellowish in white areas
Paper feels wrong
Color off in paper and printing
Hamilton and background not distinct, too dark
Ink color
69 bill--different kind of paper
Faded wrong; money doesn't usually fade. Fuzzy

0395D

Printing not sharp; too light
Paper wrong
Black ink is wrong color
Paper questionable
Portrait weird
Print in border is wrong
Color not right overall

Portrait not well done
Irregular points on green seal (not sharp)
Very obvious--looks like photocopy
Lathework, portrait dead
No threads
Looks bad overall
Poor counterfeit; grayish blacks, washed out greens
Poor central image quality
Placement of picture funny
Picture and writing look funny - something missing
Portrait not precise
Paper texture wrong
Looks funny
Printing is faint
Color is wrong
Looks real
Ink dim
Reservations about 50's embedded in border, seems overkill

0436D

Green numbers not sharp; seal also
Paper wrong
Paper color aged wrong
Feels wrong
Little threads missing
Wonder why old and taped??
Colors fade, but ten didn't - (Not worn enough)
Paper funny
Date too old to still be around
No fibers
Irregular trimming of edges
Paper wrong
Background too filled in on portrait
Lathework poor
Looks counterfeit
Bad paper
Blatant, smeared image and background
Yellow aging of paper
Creasing wrong
Feels different
Not as embellished on sides
Peculiar greenish white background
Is too dirty
Too brown
Color funny
Fine lines lack detail
Seal strange and lighter
Coloring is strange
Crooked on paper
Message at  top and  at bottom incorrect - "Will pay to bearer on
    demand" ??

Dark parts too dark
Portrait fuzzy
Overall color fuzzy
Bill has been handled many times

0759*

Jackson doesn't look good
Shading is not good (contrast)
Paper feel wrong
Dirty
Star??
Feels too smooth, too slick
Face looks wrong, not like Jackson
Feel of paper wrong
Paper texture wrong
Too much mottled area (smudges)
Paper texture wrong
Contrast in portrait wrong
Not enough fibers
Blunt points on seal
Jackson looks different
General appearance wrong
No fibers
Paper wrong
Not intaglio
Green is off
Obvious dirt is faked
Ink off creases
Black printing bad
Darker stamp of border
Dirt funny on background
Obvious poor counterfeit, xerox quality
Paper doesn't feel like the old worn bill it looks like
Feels wrong
Background has been through the  mill, but  the bill  is not soft
Enough
Printing is too dark--too black
Paper texture wrong
Color of white area wrong, border too dark
Whole bill just looks wrong
Feels wrong
Printing too dark
Eyes and other graphics strange
Overall contrast poor - printing not distinct
Discolored - paper background is dingy
Hard, nothing real obvious

1292A

Paper bad
Yellowish

Lines not sharp
Ink and printing too faint
White color wrong
Paper feels wrong
No threads
Paper not smooth enough
Portrait detail not as distinct
Numerals (denomination) over seal are too dark
Too dark color overall
Green tint overall
Print quality--not sharp
Blunt and uneven points on seal
No fibers
Franklin looks different
Poor quality printing
Flat.  Doesn't stand out (as intaglio should)
Paper also wrong in color and feel
Bad paper; scotch taped
Paper wear, fold characteristics bad
Too worn for a $100
Lettering of usa doesn't look right at top
Dark areas too dark
Line quality poor
Paper feel and tint
Detail good

1381A

All off-color
Detail poor -  not sharp
Darkness funny
Paper wrong
Yellowing of paper
Feels waxed
Looks like museum money
Color and grain wrong
No threads
Unusual color/ overall--too yellow. Faded strangely
Yellow color of paper
Overall color wrong
But also the green seal and serial # color wrong
Paper appearance poor
Printing line quality poor
Poor background color, not enough white
Paper feels funny
Grant looking at me--looks wrong
Poor quality printing
Lousy.  No lathework
Green ink wrong
Portrait flat
Paper wrong.  Everything wrong
Feels wrong; not like money

Federal reserve note writing looks much smaller than it should be
Horrible counterfeit. Overall poor definition of ink
Paper bad color, looks like high sulfur content
Creases,funny, but ink dominant characteristic
Kind of yellowish compared with most money
Brown color wrong
Dark too dark
Detail not as fine as on real bill
Yellowish coloring
Overall color wrong, even though old
Not enough green
Color doesn't look quite right, money doesn't usually lose its
Color
Play money - paper wrong color and feel
Printing too dark
Color overall
Feels ok, but thought that 77 series had different signature

2236D

Lines not clear
Ink bleeding - all one shade of grey
Black seems wrong, ink color poor
Color of paper wrong
Paper feels wrong
Paper feel wrong
Threads missing
Paper too thick
Print too dark
Paper too hard
Paper quality
Printing is different - too black (dark)
Details not sharp especially in border
Uneven points on seal
No fibers at all
Engraving not clear
Everything, lathe, portrait bad
Green color bad
No threads
Blacks not right
Darker stamped, feels right; dark too dark.
Obvious counterfeit. Poor ink quality in image and counter
Entire border poor
Paper creases
Funny feel
Big 50's funny
Detail and clarity lacking in border
Dark background so strong
Detail definitely gone
Black too dark
Printing is too dark--too black
Border too dark

Wonder if Grant usually faces that way
Border too dark (play money)
Coloring off, looks black and white
Lacks green color
Feels different
Different paper
Dark areas too dark
Green is wrong
Black is wrong.  Color wrong
Have trouble with Grant.  He has different expressions on
     different bills

3271C
Everything wrong - all color
Paper wrong
Printing wrong
Paper wrong
Color changed wrong over time
Bill seems longer (horizontally)
Color wrong
Worn, but portrait still has good contrast
Print is too dark
Color: an old bill shouldn't be so clearly printed
Printing quality poor, especially portrait
Green seal screwy, all messed up
Face looks different
No fibers
Looks phony, almost handrawn
Ink color for serial number and seal wrong
Portrait lathework wrong
Poor quality paper
Head smaller in circle
Stamped on; engraving poor; not as legible
Xerox job; engraving not there
Washed out blacks and greens
Yellow sulfur color
Creases no good
Older bills different feel; different finish on paper;, waxy,
Hard, too much so, for apparent age.,
Peculiar color.  Too putrid green
Printing not precise -  margin uneven
Printing is too dark
Color is funny
Yellow
Paper texture wrong
Print not clear (low quality appearance).
Ink wiping off, green lettering faded more than rest of bill
Printing not distinct
Paper wrong
Printed too dark
Color wrong
Portrait wrong - shadows, other

3691H

Lines bad - black gradations; but has threads
Face not clear
Photocopy appearance
Uneven points on seals
Washed out engraving
Fake threads
Poor engraving quality in portrait
Lines overly bold - too prominent
Blackness in border lacks crispness
Green color wrong
Portrait, other wrong
Paper feels too stiff and heavy
1969? Correct date?
Paper feels funny, not like money
Ok despite holes
Black seal not as sharp as should be
Not sure why uncertain
Quality better; heavier paper
Not even in contrast - one side of border looks darker
Greenish tint funny

3752F

Like copy;  paper wrong
Color poor
Detail poor
Feels weird
Face strange
Portrait distorted
Threads missing
Portrait and background blend together
Paper feels funny
General appearance wrong
Portrait is wrong (not specific)
Bad points on seal
Hamilton looks funny, eyes strange
Poor quality printing
Terrible.  Numbers lined up wrong
Ink color, blacks wrong
Paper wrong
Background of portrait wrong,
Paper cheap and thin
Bad job; central image is blurred, poor contrast,  with poor
Highlights
Fuzzy paper
69 bill; facial features--lips & nose too pronounced
Feels thin.  Awfully old
Portrait not clearly done - not precise
Border detail looks wrong

Picture doesn't seem to have right shading, not sharp image
Feels phoney - seems to have been washed, is limp
Hamilton; background dark and portrait wrong
Wonder about check # (or plate #)
Paper and ink color wrong
Portrait graphic wrong

3807A

Franklin looks bad.  Lines not clear
Paper feels grainy
Ink faint, not black enough
Paper feels wrong - too stiff, too smooth
Overall impression wrong; partly color
Printing different.  Contrast of seal poor
Gray and green funny
Overall contrast also poor
Paper funny
Paper wrong
Portrait looks different
Uneven points on black seal
No fibers
Franklin's nose looks like elephant trunk
Portrait, lathework wrong
Numbers (green) and seal--wrong
Smooth feeling
Imitated threads - too straight
Franklin looks different; mouth, pin on coat. Quality wrong
Poor definition of image
Gradation, contrast, & highlighting poor in image and in border
Size.  Too small in width
Paper texture wrong
Color is fuzzy
Not a sharp image
Looks like wrong size
Printing not right on portrait
Paper wrong
Graphics not sharp
Same hard feel as previous bill (a counterfeit)

4051D

All lines wrong
Paper feel
Color wrong
Yellowness of paper wrong
Feels wrong, like newspaper
Color wrong
Paper feels hard
Color wrong
Poor contrast in seal and value numbers
Poor contrast in portrait

Background too dark
Paper feels wrong
Not printed clearly; poor line quality in border design
Green tinge to all the background
Image doesn't look right, detail not sharp
Poor quality printing
Looks like xerox copy
Black, green, everything wrong
Printed wrong; darker, color heavier
Doesn't have right green
Terrible, print quality atrocious
Visual impression of bad, even before touching it, feel perhaps
Ok
Border too dark relative to light color - contrast not good
Has greenish cast
Something about script and face. Don't like. Detail of little
Lines too particular
Brown color
Too dark, contrast wrong
Poor quality paper, doesn't feel like linen
Lack of detail in border
Yellowish color
Feels funny
Off-color, not quite right
Paper feel wrong
Color wrong
Looks photocopied
Color wrong
Graphics wrong - mostly portrait fuzzy

4275B

Not sharp lines
Black is gray
Paper too stiff and smooth
Black ink wrong in color and intensity
Not familiar with 100's. Not sure
Contrast of 100 over green seal wrong
Portrait hazy - not good resolution
Print doesn't have texture
Line quality in borders (not good detail)
Some threads in paper, but bill looks wrong, not intaglio
Printing
12 less bold, central image mushy
Problems with federal reserve numbers--vibes wrong
Too smooth in feel
Feels funny
Little 100's
Paper feel
Lines faint, indistinct--looks like photocopy
Paper feel smooth
I see very few 100's

Stamped picture looks wrong

4967A

Black is gray;
Paper different
Seal color washed out
Engraving not sharp
Black ink too faint - especially on portrait
Overall color wrong
Too clear (light) printing
White color is wrong
Portrait and "one hundred dollars" not printed well
Washed out looking, but has fibers
Tough; portrait wrong
Color wrong on seal
Quality of paper
Franklin looks different; expression and clothes look funny
Grayishness of black ink obvious
Poor image and border contrast catches attention
Feels funny
Looks washed out in color, with background particularly washed
Out
Printing too pale.  Not enough contrast
Weak contrast
Portrait not good
Little 100's look funny
Paper feels funny
Printing is faint
Green tint overall
Counterfeiters must age them
Paper funny
Flatness of contrast in central image
Gray color of black ink
Paper doesn't feel too good
Lathework, portrait good;  feels like money but has few threads
Puzzled by Grant, but looks right anyway
Double bars over federal reserve bank number--must be ok
Reservations about 50's
Ink looks funny

6554A

Paper wrong
Detail of engraving wrong
Yellow paper; everything
Paper flimsy
Ink too light
Color of paper wrong
Paper texture wrong
Print too light
Color

Sides (left and right) differ
Printing not sharp
Lathework wrong
Portrait looks wrong immediately
Print of letters worn off
Picture looks funny
Printing not precise
Portrait seems different
Portrait looks wrong, may lack detail
Ink funny
Background looks funny
Paper looks funny
Texture wrong
Lettering has wiped out in places, ink dissolved
Picture faded
Not printed well--looks like offset
Color is wrong; graphics are ok
Printing quality off
Obvious counterfeit.  Poor quality in central image -looks
  washed out.
Guess it's OK;  Looks different.


6786A

Paper feel wrong
Yellow
Seal too dark
Printing blotchy
Color of ink and paper wrong, not white enough
Feels too smooth
Color wrong
Too dark
Paper funny
Overall color too yellow
Paper too smooth
Printing quality not good;  smeared, especially in green
Color all wrong - white is greenish
Looks like its been laundered - looks fuzzy
Paper quality wrong
Eyebrows wrong
D in federal reserve seal, and twenty on seal both crooked
Green wrong
Paper wrong
Portrait looks and feels flat
Dark print
Color of bill wrong; charcoal look wrong
Amateurish  counterfeit.    No  contrast  in  central  image.  No
Definition
Yellowish aging of paper
Smudged greens

Speckling of border wrong
Secretary of treasury's signature wrong
Printing too dark.  Too much contrast
Too dark.  Contrast too strong
Lacks detail
Ink different - too clear (weak)
Paper looks funny
Yellow tint
Printing too dark (everywhere)
Lettering not real sharp, numbers not clear
Green ink smudged on serial number
Dark areas too dark
Overall color wrong

7868A

Counterfeit; paper yellow
Different green serial #
Printing different
Paper too smooth
Ink not strong enough
Grain (texture) of paper too fine
No little threads
Paper hard
Paper appearance wrong
No threads present
Bad points on green seal
Feels papery; no fibers
Fibers missing
Central image quality wrong
Grayish blacks
Off-color green (yellowish)
Feels funny
Not precise, especially portrait
Paper feels funny
100's at bottom look wrong
Color of green in serial number and seal wrong, almost olive
Color is off
Seal is too uniform across the numbers
Portrait not sharp
Green really wrong
Portrait not bad but can't feel intaglio
Paper feels funny
Some printing also not quite right

Feels like real bill

8194A

Paper thin and fragile
Not sharply etched
Paper wrong, too thin

Paper is too light
Paper feels funny
Paper texture funny
Paper texture wrong
No fibers
Grant looks too stern
Poor quality printing
Portrait wrong paper
Green ink wrong
Lathework wrong
Poor quality paper - tears
Seems too thin for real age
Printing too dark
Too worn for $50
Paper feels funny
Paper too light
Paper feels funny
Green-gray has too much contrast
Portrait is not as sharp
Portrait engraving, poor highlights, poor border
Ink definitely smudged
Creases and folds wrong

9111B

Yellow paper
Image wrong, bad in general
Paper feels wrong, weak, like newspaper
Color of black ink and of paper are wrong
Color wrong
General appearance
Paper quality wrong
Contrast wrong;  too little gradation in shading
General appearance
Terrible.  Lathework and portrait look like xerox
Terrible paper.  Print comes off easily
Picture wears off--looks bad
Feels really funny
Yellow paper color
Darks too dark
Dark around border
Overall color wrong
Scroll details seem wrong on sides.
Paper texture wrong
Paper doesn't have right feel, is falling apart - maybe  bill was
    washed
Paper feel
Looks like photocopy
Portrait not right color
Hard to tell if wrong
Poor detail on green seal
Background color wrong, looks funny

Color is too yellow
Terrible quality of printing
Paper poor--has cardboardy feeling
Feels ironed;  gut feeling that it's bad

9197C

Wear pattern wrong
Paper feel wrong
Engraving bad.  Looks photocopied
Paper feels weak
Color is wrong, despite age
For a worn bill, the ten on seal is still quite even and not worn
Paper hard
Overall color wrong
Color wrong
Ink has bled into white background
No fibers
Needs date at bottom of seal
Washed out, especially portrait
Terrible.  Black filled in
Green is yellowish
Poor detail
Paper poor quality
Quality of paper and print bad
Engraving quality poor
Hamilton is frowning
Extremely poor engraving; ink, printing wrong
Creases wrong
In such bad shape.  Feels funny
Too dark around border
Not sure whose portrait is meant to be on the bill
Dark around borders
Paper feel wrong
Printing too dark
Overall tint is wrong
Face not clear
Very faded and worn
Ink different color and lightness
No reason to reject

9235A

Image contrast and clarity poor
General quality poor
Ink on paper too faint
Paper feels wrong
Overall color wrong
Print looks strange
Mottled areas (smudges)--referred to it as ink
Paper texture wrong
Contrast in portrait wrong

Irregular points on green seal
No fibers
Triple chin on Franklin
Paper wrong
Printing wrong (particularly lathework and portrait)
Poor quality paper
Too much wear. Heavy enough but not enough detail
Print not good
Looks like a xerox
Black ink is grayish
Image quality of portrait poor, lack of crispness
Border poor
Losing some of its color with age
Needs better paper
Looks dirty. Not right
Ink washed out
Gray looking
Overall impression wrong, but nothing specific
Ink has faded; has been washed
Ink wiped away from picture - picture may also be wrong
Paper wrong
Fake dirt smudge
Too white. Light printing and background lacks color.

9428A

Paper wrong
Clarity, color wrong
Green numbers not sharp - not etched--printed other way
No threads
Paper feels funny
Discolored area--looks like dirt
Overall quality of engraving
Paper feels funny
Shouldn't discolor in only one place
Paper wrong
Lathework dead, unclear
Green ink wrong
Portrait wrong
Vague feeling about engraving in center, lack of contrast--like
    looking at painting in the dark, no highlights
Printing too dark
Overall appearance wrong.  Maybe contrast??
Ink color overall wrong
Feel of paper--slick
Worn; hard to tell
Printing under "For all debts" poor but may be BEP press defect
Did not look as detailed as it should

COMMENTS ABOUT GENUINE BILLS

0046A

Paper seems strange
Borders look funny
Paper feels funny
No fibers
100 and seal not aligned
Good copy - paper texture added - fake, doesn't feel like
    intaglio
Feels counterfeit; quality of the paper thin
Way paper has crinkled, more like cardboard
12's vary, etc
Paper texture wrong
Too much detail in lines on border
Nothing striking
Wonder about check # (or plate #)

0100A

Not enough fibers
Poor central image and background gradations, but could be good
Background seems a different color
Printing not sharp
No threads, but ok
Good blackness of ink. Paper feels right.  Lathe a bit off
Feels, looks real

0107A

Paper too smooth, lightweight
Paper funny
Bends, folds not as durable
Poor engraving - weak blacks
Little 100's strange
Looks real
Margins don't seem to be even
Green color seems wrong (tint)

0267A

Paper funny
Vertical lines across bill
Portrait quality
Alignment of seal
Poor contrast with central image
Weak blacks
Paper a bit smooth

Worn but real
Folds sharper

0716B

Looks funny
Ink smeared at bottom (in twenty dollars)
Threads pulled out of bill
Unsure - paper too thick
Three defects in portrait background, also vest defect
Printing not sharp enough (stray ink)
Flexible bends good
Just realized scroll is correct
Overall tint

0768A

Printing defect in background of portrait
White area wrong
Printing around jacket looks irregular
Are Ortega and Regan on the same bill?
Paper a little thick
Paper texture wrong
Signature on left looks wrong
Misprinting in portrait background
Looks right, feels good
Noticed a color detail not previously noticed
New bill, threads, good paper
Better quality; print not worn down

0934A

Paper too hard
Franklin has broken nose, excellent counterfeit, otherwise
Looks too perfect.  Suspicious of 100's
Not used to 100's - counter 100 seems weird
Paper wrong
Good overall impression.  (New is easier)
Looks real

1139B

Feels too smooth
Looks a little big, and margins unequal
Paper funny
No fibers
Paper feel wrong
Blunted points on seal
Too thin
Lack of highlights in central image
Looks funny; top 50's so much larger than bottom ones

Federal reserve too small at top - perhaps should be usa
Paper feels bad
No threads
Not sharp
Portrait looks worn, but bill is worn, therefore ok
Portrait jumps out; paper feels better
Greenish cast to paper

1227A

Don't like feel (too papery¦)
Impression of central image wrong - has poor highlights and
Contrast
Has threads.   Looks good, not sure now
Looks and feels real
Not fuzzy; no misspellings;   signature correct for age

.1235A

Green not sharp (white area) - not inked well
Paper texture wrong
Paper is strange
Paper too smooth
Discolored area that doesn't seem like dirt
Excellent counterfeit, grayish blacks
Paper creasing
Lack of highlights in central image (flat)
Feel of paper wrong
100's at bottom look odd
Paper wrong
Printing not right
Dirt smudges
Paper feels like paper, not like cloth
Threads present; portrait ok.   Can't feel intaglio as well.
Franklin looks different
Funny feel
Feels thicker
Washed out but ok

1278B

Stray printing again (ink where it doesn't belong)
Paper funny
Ink shows through from back
Counterfeit due to narrow borders.   Gov't should do better
Margin not even
Contrast too strong
Face looks splotchy?  Maybe they all look like that
Feels funny

Also detail is not quite right
Color too white
Ink is too black
Generally looks for detail, misspellings, fibers, paper feel
Very good bill

1372A

Paper low quality
Wear pattern wrong; but image clear
Paper too thin; not strong enough; rips too easily
Portrait not clear
Uneven points on seal
No fibers
Generally good, but green is off
So is paper (off)
Bad quality; very thin paper
Hamilton looks different
Obvious counterfeit; lack of gradation in background; lack of
Highlights
Fold quality wrong - is too soft
Paper too thin
Paper wrong
Hamilton's lips look funny
Feels fine but detail of edge border seems larger
Feels different
Looks like it's been through the mill

1695A

Paper lightweight and flimsy
Crease of paper
Flat contrast of central image
Paper is thin, but looks ok
Worn, but looks good.  No threads, tho.  Green good
Better Hamilton; ok

1741D

Green numbers bleed and federal reserve note printing blotched
Ink seems wrong color - too much black, too much contrast
Much of the detail is not good, printing not sharp, looks like bad
Photocopy
Seems washed out, lack of contrast with background
Different color--too white, too new
Too dark (printing)
Too dark on border areas
Printing not distinct, especially at top
Paper ok
Contrast too strong
Poor quality printing

Bleeding on top like a good one.  Paper correct
Portrait intaglio.  Lines a bit too thick--too much ink
Feels real
So different from previous  bill (worn 20)
Graphics of portrait not as real
Black tint off

1885A

Never noticed plate (?) numbers before (little ones)
Newer 50.  Many threads.  Paper, portrait good
Looks and feels real
Snappy colors and engraving
Like Grant better now
Have reservations about 50's

1941D


Seems long
Excellent counterfeit.  Weak green ink
Federal reserve heading, background fuzzy
Contrast too strong.  Portrait too dark
Signature looks funny particularly 1
Paper not quite right
Printing not quite right
Some printing is smeared, especially washington
Color off
Too much ink, but looks, feels real.  Threads present.

1942D

Not sharp; ink bleeding; signature bleeds
Paper feels wrong
Green didn't print well on federal reserve note
Excellent counterfeit, like image, but doesn't appear real
Color on words not uniform
Too much contrast in background vs. Border
Printing not clear
Feels like real thing but federal reserve note  printing squished
Black ink bleeds, portrait feels like intaglio, threads present

2119A

Paper funny
Not enough contrast
Thought they were more green; shading, details good
 expected more green on bill (unfamiliar with 100's),
Blacks not very dense.  Printing varies
Paper feels right
Not familiar
Feels real (but all c-notes look funny).  Green looks right

2136B

Paper funny
Points blunted on black seal
Can see through counter numbers on seal
Beautiful counterfeit.  Defect on cheek
Background too plain (white) and green seal too bright
Coloring funny, shading not exactly right, don't see many 100's
Mouth is wrong
Hard to tell; edges not sharp but paper is good
Paper too thin
Newer is easier, looks easier--all features and threads good
Feels, looks real

2507A


Dirty one; stiff, paper seems real; clear detail
Wouldn't accept myself;  dirt covers too much
Wouldn't accept this bill; can't see seal, etc
Paper and stain funny
Dirt area--a real one wouldn't circulate like that
Wrong picture?
Grant partially obscured; doesn't look right
Hard to see picture.  Doesn't look like him, but can't see enough
to be sure
Dirt area bad
Green a different color, shows up bolder against dirt
Wouldn't take it but thinks its real, paper right
Don't like mutilation.  All features, bleeding also
Graphics in center and border legends funny; wondered about 1's
Dirt caused problems
Too dirty to tell, especially portrait.  Don't want to decide
Dirty one - hard to tell
Printing not distinct

2679A

Texture wrong
Uneven margins
Blunt points on seal
Not enough fibers
Holes in it
Background and overall image,  focus on  portrait and  on 2-color
overprint
Back of jackson's collar looks funny
Margin wrong
Numbers in corners look funny - too much contrast
Signature bothers
Bill itself is crooked, chopped off and misaligned
Hole in head

Green numbers too light - vary across bill, not raised enough
New--too smooth?
Feels good
Paper good
2792A

Paper wrong
Image not sharp; portrait poor
Paper funny
Problem with green seal points
Doesn't seem like intaglio printing
Green color is perfect, but numbers not straight
Paper is wrong
Lack of central image highlights, blacks not dark enough
Noticed franklin's double chin
Hard to tell
Overall tint is a little wrong
Feels, looks real
Realized that small 100's were right after all
Felt ok

2844A

Paper looks wrong
Paper feels too slick
Paper funny
Blunt points on green seal
Paper wrong.
Folds too crisp
Cheap feel
100 and seal not aligned
Color for age not right
Good
Good paper quality, feel, gradation of graphics - all good

2860A

One flaw area in portrait
Paper funny
Poor rag quality
Obvious dark quality fibers
Defect in background image (not dirt)
Off-center both ways, but good contrast
Too good, too clean, too new
Margin is not even
Poor job printing green seal, not enough ink
Smudge on portrait background--is it printing or dirt?
A little light
Paper good. 100'S look different from others
Good print and paper
New ones seem different, somehow

2885A

Paper wrong
Image sharpness poor overall
Paper feels funny
Bad points on seal
No fibers, face OK
Crisp; would tear too easily
Too dark (printing)
Ok, but guessing; not good vibes, feels different
A little too black
Paper has long funny creases
Paper, green ink good

2998B

Paper feel and quality poor
Too much discoloration and smudges
Paper dirty, hard to tell when old
No fibers
Paper is bad
Black is not black enough
Junction of coat and background, poor highlights and contrast
Looks like it's been driven over by a truck
Border design seems wrong
Paper funny
Dingy background
Dirt makes it questionable
Looks like good, worn bill

3157A

Threads missing
Paper stiff
Seal bleeding
Blunted and uneven points on seal
100 and seal not aligned
Can't feel intaglio.  All 100's bad for that
Quality of paper poor
Dark color and wearing off.  Print, features worn
Obvious.  Lack of crispness in central image
Lack of crispness in federal reserve seal.  Border engraving better
Top 100 not same as bottom 100

3251A

Waxy; paper quality poor
Paper too smooth, not substantial enough
Portrait not clear
Threads missing
Blunted points on both seals

No fibers
Paper worn badly.  Is fuzzed
No threads
Looks real; but thin paper which would tear easily
Poor highlights in central image
Folded creasing
Slightly gray blacks
1's in serial number just don't look right, too square
100's different in background relative to face
More variability in dark oval area. Different from previous 100's
Feel of paper is a little wrong

3267C

Printing blotchy; green numbers not sharp
Ink smeared on washington
Very dark relative to the other bills, but feels right
Excellent  counterfeit.  Top  and  bottom  headings  blurred  and
spotted
Slightly washed out green
Contrast too strong.  Spotty ink on bottom
Dots  in  areas  not  supposed  to  be  printed. Printed lines not
always straight
Paper funny
Paper feels funny
Too much ink; green ink is too light, but bill ok
Banner must be ok
Looks ok

3297A

Harder when old; paper yellowed
Paper too thin
Color hasn't aged properly
Color completely wrong
Face; worn bills quality differs
Smeared image
Yellow color
Don't like color (green background color)
Too brown
Yellowed
Color is wrong; graphics are ok
A little dirty for 1977
Paper is worn
Dirty but looks good.  Very soiled
No threads - harder to tell with old bills
Looks at patterning--different bills
Color strange;  detail good
Yellow paper unusual

3494B

Not etched well; green numbers have hollow space, bleeding
General impression
Uneven points on green seal
Holes, good quality image
Too dark;  too much contrast
Too much contrast;  too strong
Paper feels wrong
Too many stray ink markings
Real, because black ink bleeds, threads present
Feels like the real thing; better quality paper
Looks ok

4108B

Not etched well; printing of letters poor
Threads there but could be fake - too many
Paper feels like regular paper, not like $ bill
Some fibers, but feels wrong
Border a little too wide
Lines too well defined
Margin wrong
Too much contrast
Paper texture wrong
Clipped 5 in lower right is questionable
Trimming of edges is irregular
Paper and threads good. Portrait ok
Real

4296E

Paper not right; some thread there; wear pattern wrong
Portrait off; detail ok
No fibers
Bad points on seal
Lack of fiber
Irregular engraving on coat
Difference in quality of print.  Features wearing easily
Very subtle central image problems, lack of crispness, highlights
Crease in center of paper seems wrong for real money
Paper good, intaglio, ink portrait good
Just noticed large edge borders
Secretary of Treasury was Miller??
Background too white
(Just realized who is supposed to be in the portrait)

4317C

Threads missing
Background of portrait is too uniform
7's asymmetric, not all the same boldness
Feeling paper--harder to tell when worn
Texture slick, waxy, too smooth

Hamilton's nose looks wrong
Outline of large ten in seal funny

Looks worn but genuine.   Portrait still good, no threads--ok
Feels real; more durable
Looks real

4723A

Paper waxy; paper in general poor
Paper too slick
Paper feels wrong
Paper wrong
Overall coloring wrong
Not enough fibers
Paper feels funny
Paper wrong--worn fake
Black ink is grayish
Central image lacks crispness
Uncertain due to extensive soil
Paper feel and printing feel
Can't tell with 100's
Fibers not there
Franklin's name worn
Suspicious naturally of 100's
Green is smeared across white
Tinted strangely

4869*

Yellow paper
Paper feel wrong
Star??
Has yellowed funny
Looks fake, has aged wrong
Color and grain (paper texture and threads) wrong
Fading is unusual color--yellowish
Overall color (yellowed)
Face looks different
Paper deliberately worn.   No threads, too worn to tell, though
Would tear if folded too much
Paper folds funny
Peculiar color--so yellowish
Star after serial number looks out of place, unsure
Graphics ok; color wrong
Paper funny
Fiber not visible--hard to tell since worn
Appears very dark as though drug through mud
Old and yellow; hard to tell

5178B


Bad paper, funny feel
No fibers
Ten not aligned with seal
Way it's printed - too heavy - but wouldn't wear right
Central image lacks contrast in highlights
Sides seem wrong - not enough detail
Paper a bit smooth
Paper texture wrong
Lathework, portrait background good


5311A


Color of money wrong
Feel wrong
Margins very unequal
Paper feels funny
Margin off center
Overall printing is too light
Points on black seal wrong
Borders really off-center
Portrait is looking at me - seem funny
Lacks fibers
Trimmed unevenly
Poor ink definition.  Poor contrast federal reserve seal
So far off-center in vertical direction
Don't like narrow border on top
Margin wrong
Border too light
Too much space at bottom, top cut off, not centered right
Green is good but bill is off center - something is wrong
It's very light, though
Margin too far off center

5318B

Color? Overall impression wrong
Paper funny
Blunt and uneven points on black seal
Slightly different feel
Background washed out but border ok
Too light in border
Paper feel wrong
Printing too sharp and too much contrast
100 and seal not aligned
Looks good, but $100 bill looks wrong anyway--is too little
Head looks too big, but feels real

Ok
5372A

Paper too slick
Different color where diagonal line is (upper left)
Doesn't look so bad.   Threads   look   black.   Portrait   good, but
lathework poor
Bill has been through the mill; tears easily
Low contrast of central image and border, gray ink
Margin not even
Paper feels funny
Bill printed off-center; more space at top than bottom

5654A

Paper too smooth for age
Paper funny
Grayish black
Creasing
Slight low contrast central image and heading banner
Lacks clarity in face
Feels wrong--too much body stiffness
Old, worn. Portrait background, lathework, green color good
  harder to tell with old bills
OK

5802A

Totally confused; also face and suit he's wearing wrong
  texture of fabric not convincing
Portrait wrong
Lathework wrong
Green numbers and seal wrong--too smooth
Imitated threads--too straight
Fold would tear easily
Very subtle.   Moderately good highlights and contrasts in central
image
  not as crisp as it should be, though
All 2's not the same
Fiber sticking out
Tint is questionable
Darker stamp but looks real

5925A

Paper feels funny
Creasing wrong
Green numbers are too thin
Color wrong
Bill doesn't look like intaglio
Folds funny; real easy to tear
Paper folds funny

Faces start to look different
Fibers missing
Numbers in corners don't seem correct
Tint is a little off
Feels better
Feels ok

6092A

Impression of central image wrong
Printing defect in background
Some fibers
Lacks threads but good portrait
Scans bills for serial #'s the same, overall feel, color
  lettering not fuzzy, misspellings, signatures correct,

6101B

Serial numbers not sharp
Lack of contrast central image
Green ink not very green
Contrast too strong - printing dark
Printing not right overall.
Jackson looks different
Borders of bill askew--too much white on one edge
Blurred washington, d.C.
Trimmed unevenly
Seal area looks funny
Tint is wrong
Feels new, but doesn't look right
Reservations about lack of white border at top
Too much black
Tint is wrong
Real but ink is too heavy
Printing much better

6228C

Ink in wrong places - dark spots, as if bad printing
Eyes; ink shows through from back
Uniform background
Stray dots - wonder if real
Well-used, but Hamilton looks good
Looks real
Like this one

6295E

Portrait and border not good gradation of black and grey
Colors too yellowed - looks fake - paper looks wrong
Paper feels wrong
Color wrong and missing threads

Overall color--yellowed
Paper texture wrong
Hard to tell with old bill
Points look worn through paper
Paper looks and feels wrong
No threads but good appearance
Central image, background detail poor
Usa banner poor
Paper creases
First 3 letters of signature too large, stand out
Paper thin
Printing too dark

Only color wrong - graphics ok
Worn
OK

6381B

Doesn't look right; overall impression wrong

Purple stamp; has threads; intaglio
  paper good; green color a bit off, but ok
Mole on Grant's face - never noticed before
Good
Grant looks better

6592B

Paper funny
Excellent counterfeit - but green is off-color
Blacks slightly gray
Portrait, lathework good
Green right color. Decision easier when bill not worn
Feels real
Are there supposed to be 50's on the side and bottom?
  There is no pattern between denominations
Color and paper ok

6854C

Blunt points on seal
More shading outer oval
Fold in middle looks funny
Serial # crooked and c's look funny at end of #
Good? Hard to tell
Color of paper a bit strange
Tint seems too greenish
Worn, some threads
Feels good
Small wrinkles compared with long defined wrinkles on bad ones

6919B

Stray marks - looks like it's bad printing
Paper appearance wrong
No threads
No fibers
Grayish blacks
Margin uneven
Stray dots printed on bill

Feels more like real bill; portrait, lathework good
Felt ok

7104B

Too hard paper
Feels papery
No fibers
Creased wrong
Wears badly
Funny black threads, but portrait, feels like intaglio
Troubles with 50's; worn in center
Smudging of ink, maybe dirt, close
50 in upper left larger than in upper right, upper set of #'s
crooked and larger,
Paper thick, but wear is like good bill
Maybe thick paper?
Overall appearance?

7144B

Paper feels funny
Something about face
Paper texture wrong
Unclear printing
Color of dark areas seems wrong
Threads, paper good but green a bit off
No clip on 5; good gradation of grays in background, vest of
portrait hits you
50's in side legend don't seem to belong
Darkness is strange--too new looking
Feels real

7183A

Green numbers aren't well etched - lines not sharp enough,
   numbers bleed
Paper too thin and stiff for age
Paper funny
Too much shading--looks like dirt, but seems to be printing flaw
Bad points on green seal (twisting around)
Print too light; engraving not as clear as should be

Problems with Federal Reserve number
Feels too smooth
Overall appearance wrong
Noticed bottom border--seemed unusual
Phoney due to 100's on edges of bill
Getting confused with so many bills
Dirt smudged
Threads present; portrait ok

7234E

Yellow
Paper feel wrong; inking is ok
Feels like newspaper
Overall color poor
Hard to see fibers on this dirty bill
Portrait not quite right
No fibers
Paper--worn deliberately
Green numbers not straight and wrong color
Color is wrong.  Too worn to tell
Feels ok; color wrong
Obvious counterfeit - crudeness of background
Color of paper wrong (old but aged too yellow)
No threads
Looks ok

7293*

Star?
Green numbers different.  Fatter
Washington, d.C. Above seal isn't aligned straight
Excellent counterfeit, grayish blacks
Paper creasing
Star after serial number doesn't look right
Worn but real
Banner looks funny; guess it should be there
Old money causes problems in color and feel

7333B

Doesn't look engraved; not uniform appearance
Individual, features  ok.   Too   much   contrast overall (too white
background)
Threads there, portrait ok, but hard to tell
Feels right
Stamped ok
Looks ok

7405A

Not sure why; one flaw area

Paper feels hard
Blunt points
No fibers
Very good phoney.  Ink not piled up
Black not so black, white lines not good in detail
Feels too stiff; not like money
Federal reserve printing different
New - more difficult when new

7632E

Good counterfeit.  Federal reserve seal blurred.  Portrait vague,
  tho good
Paper feel
Signature for Secretary of Treasury looks wrong
Paper ok
Paper feel
Worn, but ok.
Feels more like real dollars

7701A

Paper too smooth
Paper funny
Not enough fibers
General appearance
No fibers
Washed out blacks
Looks light compared to previous bill (counterfeit)
No threads
Paper questionable
Different feel but ok
Seems real

7741B

Hard to explain; not sure
Paper funny
Printing not quite clear enough
Paper feels funny
Are there supposed to be 50's on the side?
Bill in good condition
Good

7921B

Portrait very  distinct.  Background  doesn't blend  in as much -
  too outlined
Looks good but paper has dark fibers
Ok
Portrait jumps out.  Paper feels better. Looks for  greenish cast
to paper

Didn't know money was so different for each denomination
The united states looks funny; not sure what 50 looks like

7949B

Paper feel wrong
No threads
Not enough fibers
Quality of paper; old
Fairly decent counterfeit
Lack of highlights and gradation in central image and background
Paper wrong, but portrait good, etc
Looks washed or something

7968D

Printing quality not good; Washington, D.C. especially bad
Washington, D.C. above seal is blurry
Good counterfeit. Blurring of border at top of federal reserve
 note printing
Slightly grayish blacks
Breaks in underlining below image
Feels ok; but banner at top looks wrong
Jackson's eyes; some other lines not clear
Looks very good
Stamped on correctly
Good

8081A

Margins unequal
Face weird
Paper funny
Uneven borders
No fibers
Excellent counterfeit, hole in forehead
Vague feel
Lack of contrast - black has grayed
Don't like narrow border
Uneven margin. Not centered
Irregular edge trimming
Margin off center
Out of alignment

OK
Green color good. No threads, but knows they can be sparse.
Lathework is good
Feels, looks good


8350A

Wear pattern on edges funny
Sharpness of engraving lacking - 11's not clear
Paper texture wrong
Paper feels funny
Bad points on seal
Bad quality paper; torn edges
Feel of paper
No fibers
Worn, but feels right
Quality of central image and print is good

8361A

Counterfeit - not sure why
Bad points on seal
Feels slightly funny
Smudged 5, good counterfeit
Contrast too strong
White seems too bright
Wrong signature, treasurer is different
Lines of Hamilton's face and other lines seem wrong
Paper too smooth

Paper feels right
Purple numbers.  Looks good
Paper better quality; looks good

8389F

All #'s not the same; triangle not printed sharply
Federal reserve not clear.  Other lines are sharp
Texture wrong;  paper too thick
Paper too hard
Uneven points on seal
USA banner poor
Poor detail on central image
Felt thicker
Too light
Face is missing some lines; not sharp printing
Green through gray.  Gray  looks too deep, less transparent than
    usual
Jackson looks washed out
Feels good (paper) numbers, etc. Right. Green is a little off
Color darker in border and way stamped, feels real

8638C

Paper too light in feel, too thin
Color weird
No threads
Appears intentionally darkened
Fades with unusual yellow color

Color (aged) - looks faked
Paper thin
Blunt points on black seal.  Old ones difficult
Quality of paper wrong
Jackson's hand not in correct place (compared to other bills
Paper bad
Contrast (black) bad.  Intaglio not there
Looks smaller
Federal reserve note printing squashed up
Way paper has crinkled, feels softer and fuzzier
Dark printing
Paper aged
Paper feels funny
Dirty/old.  Sepia color
Color looks wrong (overall)
Looks ok
Seems awfully beat up, but still real
More concerned if bill is new - feel more sure with old ones

8686B

Paper too light in feel
Colored fibers missing
Quality of paper poor.  Wouldn't take many folds
Obvious. Central image poor
Creasing
Smudged, slightly gray blacks
Hamilton looks funny
Paper feels too light
Much used; portrait and lathework good despite age
Has been around a long time, but is ok

8731A

Paper too stiff for apparent age
Paper funny
No fibers
Doesn't usually carry 50's--USA printing looks funny
Portrait, lathework good.  Green right color
Feels ok
Good
Reservations about 50's in corners

8777A

Paper bad
Paper too smooth
Color too green overall
Paper funny
No fibers
Bad points on black seal
Paper doesn't look right

Nose wrong; no mole on face (had seen one on  a bill  he was sure
   was good)
No fiber
Green good, but no threads
Paper wrong
Bad quality paper
Poor counterfeit, smudgy printing job
Gray image looks fuzzy
Lettering at top too small
Big 50's funny
Overall color.  Greenish tint

9052A

Prominent green parts - high contrast (seal and serial #)
Unsure about paper, no fibers
Folds are too crisp.  Tears too easily
Creasing qualities of paper
Feels funny.  Too rough
Crazy fifties, Federal Reserve note printing too small at top
Paper feels different; not same graininess (threads)
Paper a little light
Beat up, but paper feels good; lathework, portrait ok



9139B

Paper feels waxy
Appearance is ok; no threads
Looks worn, but paper is too stiff
Blunted points on both seals
Background engraving gradations, lack of highlights
Creasing wrong
Border too dark
Paper good, portrait good, but not quite right. Threads present

Feels real
Some have letters and #'s in bottom corners

        9159A

Portrait bad
Paper bad; wearing pattern different
Worn, printing not well aligned
Blunt points
No fibers
Paper wrong
Blacks wrong
Doesn't seem to be a quality note
Looks like it would tear; cheaper paper - not as durable
Poor paper quality

Border is too narrow
Expect new $100.   Would question
Feels a bit funny

9265A

Paper too lightweight
Poor quality paper.   Weak at fold
Flat image quality.   Gray ink
Old

Well used.   Lathework, portrait good.   Only see one thread
Reservations about 50's in general

9602A

Ink bleeding
Portrait looks fuzzy--like photocopy
Paper wrong
Color of printed areas (all) wrong
Green ink smudges on white areas
Green dye faded into background and worn off in places
Don't like his hair
Face--engraving not sharp
Smeared green ink.   Has threads, though
Too papery; not durable enough
Poor quality of printing and background shading, ink is smudged
Paper seems too heavy for apparent age and degree of wear
Contrast is too weak
Green rubbed on to white area
Little 100's in legend printed at bottom look wrong
Looks too old; hard to see printing
Feels a bit strange
Old bills hard.   More normal white border

9695A

Color wrong
Border, black ink looks wrong.
Fiber coming out of paper
Right eye wrong, half closed
Cross-eyed grant
Fuzzes, creases off
Purple numbers present. Paper wrong, mostly
Poor quality; tears easily
Poor ink definition - weak in contrast
Fold qualities not true
Feels like money
Border ok
Looks ok

9882B

Paper funny
New, but paper doesn't feel right
Unfamiliar with 50's
Not enough fibers
Paper feel and printing too sharp

Uneven points on seal
Generally examine color and intensity of ink, feel for age
Intaglio feel.  Threads present
Looks and feels real
Good, image quality crisp

Table 3 - Decision Processes Reported by Participants During
Debriefing


Participant 1

Most  noticeable  is  an  overall  impression of  the  sharpness of
lines
Feel of paper
Yellowed color
Line sharpness and quality are particularly variable across bill
Color of green seal
Portrait quality
Presence of threads
Numbers in central area

Participant 2

Most noticeable is the look and feel of the paper
Color is also important
Feel and color relative to apparent age are also important
Presence of threads may be helpful, but they  are hard  to see in
old bills; they are more obvious only in new bills

Participant 3

Look first at bill denomination in upper right-hand corner
Looks second at value of the bill printed over the seal;
  here  the  contrast  of  the  gray  against  the  green is most
important
Looks third  at the  portrait and  wear pattern.  These should be
  even despite age.  Portrait-background contrast should be sharp
  and any fading should be uniform
Tried  looking  at  engraving  in  border but didn't find it very
useful
Found the most trouble occurred with creased and worn bills

Participant 4

Began by looking at detail carefully
Later looked at shading and contrast and
  felt real bills have most gradation
Looked for threads
Found older bills harder
Paper should have semi-rough texture

Participant 5

Looked for blunt points on seals and lack of fibers
Color often not white enough with blacks not black enough or fine
  enough
Jackson frequently looked fake, with closed eyes

Table 3 - (Continued)

A real bill should be grayish because of fine lines
Dirt causes color problems, while washing bills causes problems
with fading
Noticed much variability in portraits with some lacking a great
deal of detail. This was particularly true of Jackson

Participant 6

Looked first at overall printing quality, where defects were
some times quite obvious
Looked for colored threads, but had trouble finding them in worn
   bills
On a worn bill, looked at engraving, especially the details of
   the portrait
On a new bill, easier to look at quality and find fibers
Found much smeared ink, particularly "Washington, D.C." above
seal
Treasury seal should be aligned with denomination -
   easy to spot, but not most important
Trimming of bills is worse on new ones
Noticed more details as experiment progressed

Participant 7

Black printing and lathework should be clean and heavy
Portrait should also be clear
Paper should feel right, with feel being a good diagnostic tool
Hue and type face of green printing also important

Participant 8

Most important - focus on portrait crispness vs. fuzziness
Central image (portrait) should have subtlety and sharpness in
contrast
Became more critical of color and density of black and green inks
Looked at thin lines at top and bottom of bill
Aged color appearance was a strong factor in older counterfeits
Creasing was also a strong factor, although less so with new
bills
Density of blacks also important
Background engraving important along with white holes around
portrait

Participant 9

Examined portrait first
Found general color and overall contrast important
Margin size important - varied frequently
Not always easy to tell, but the easiest cue was
   that printing was too dark or too light in color

Table 3 - (Continued)


Participant 10

General color of paper important - odd if very yellowed
Variations in detail of border very easy to detect (50's in $50
bills)
Feel of paper - should not be slick, coarse, or grainy
Looked more at borders, and treasury seal
Would have passed much of the currency in a real situation

Participant 11

Feel important
Serial numbers should be the same and lettering should be uniform
Edges should be uniform - some were way off
Color of green ink often blurry, but not the same as when washed
Checked for accuracy of signature (e.g. Regan on '81 bills)
Fuzziness is a positive quality - money usually stands up well
Texture and color, fading and shading are most important
Noticed a $10 with wrong writing
A lot didn't have enough green; color appeared wrong due to dirt,
   perhaps an illusion.  Very hard to determine with older bills

Participant 12

Feel important
Overall appearance of printing quality, especially contrast -
   noticed if too heavy rather than delicate
Some bills were aged too much - as if intentional
Rough areas occurred - looked for stray in counter zeroes
   and lack of sharpness
Bills often not centered on paper - an easy cue,
   but may not be useful
An aged bill should all blend together -
   should not appear intentionally aged

Participant 13

Color of printed border and other designs examined first
Looked at background contrast along with trim - often obvious
General appearance important - if graphics wrong, obvious
counterfeit
Overall color made it hard to tell, especially if worn and aged
Thickness of paper varied and made decision difficult
   paper tends to fluff when aged
Gradually became less skeptical of new bills being too thin

Participant 14

Color variations easiest to detect
Threads were missing on too many bills
Much variation in texture and feel of paper
Year and wear should go together with color vs texture being
compatible (e.g. bill should be soft if old and worn appearing)
Always looked at portraits

Table 3 - (Continued)

Noticed that ink on printing smeared sometimes

Participant 15

Hard texture of paper and engraving of border
Overall lightness and darkness of printing
Apparent age and wear for year printing
Printing quality was hard to tell in general
During the experiment, changed perception of texture,
    and noticed more engraving

Participant 16

Overall appearance and color most important
Feel of paper important
Noticed any unusual printing, discolored areas, and inconsistencies
Serial numbers were sometimes too yellow
Rarely looked at line quality or portrait

Participant 17

Quality of paper in bends and folds, as well as easiness of ripping
Quality of engraving and overall legibility
Thin feel, more like paper than like money
"Federal Reserve note" engraving varied with bills - sometimes too narrow
Color of printing, as well as darkness and heaviness of ink
Ink sometimes wearing off
Features of both Franklin and Grant seemed to vary
Paid more attention to printing quality and less to actual writing

Participant 18

Clarity of background and face detail important
Centering of bill and margins varied
Overall color and shading varied
Noticed nature of paper (run fingers over bill to tell)
Noticed contrast and clarity of detail as a function of age
Became more familiar with bills, noticed darker outer borders

Participant 19

Noticed feel, color
Detail of printing - some bills were too detailed
Some margins were too narrow
Contrast of printing on paper was often too much or too little
Wear wrong - bill was too beat up for date
Portraits often didn't look right - faces seemed to differ
    (but unfamiliar with $50's and $100's)
Noticed uneven borders right away
Background color way off - white wrong

Table 3 - (Continued)


Participant 20

Mostly overall color and contrast
Paper feel
Seemed to get harder -
   became less sure of what real bills should look like
Medium wear bills looked best

Participant 21

Paper texture important for most bills
Clarity of print quality
Unusual coloring and aging
Looked at bill overall rather than at specific features
Checked portrait for accuracy
Became more  tolerant of  differences in  printing quality during
experiment

Table 4.  Measured CIE Chromaticity Coordinates and Luminances for
          Counterfeit Bills Used in Pilot Study

| Denom | RP# | Serial# | Descrip | x | y | u | v | Lum |
|-------|-----|---------|---------|------|------|------|------|------|
| $20 | 103 | 6786A | lathe frt | .4636 | .4239 | .2590 | .3552 | 22.0 |
| $20 | 103 | 6786A | white | .4749 | .4304 | .2633 | .3579 | 106. |
| $20 | 103 | 6786A | green | .3867 | .4902 | .1908 | .3627 | 23.9 |
| $20 | 103 | 6786A | portrait | .4618 | .4217 | .2588 | .3545 | 21.2 |
| $20 | 103 | 6786A | blk letter | .4603 | .4180 | .2594 | .3535 | 13.8 |
| $20 | 104 | 0759* | lathe frt | .4631 | .4236 | .2588 | .3551 | 34.0 |
| $20 | 104 | 0759* | white | .4746 | .4278 | .2642 | .3573 | 81.5 |
| $20 | 104 | 0759* | green | .4015 | .4805 | .2017 | .3621 | 40.1 |
| $20 | 104 | 0759* | portrait | .4627 | .4231 | .2588 | .3550 | 29.5 |
| $20 | 104 | 0759* | blk letter | .4568 | .4199 | .2564 | .3536 | 16.4 |
| $50 | 15 | 2236D | lathe frt | .4631 | .4206 | .2601 | .3544 | 18.2 |
| $50 | 15 | 2236D | white | .4657 | .4267 | .2591 | .3561 | 121. |
| $50 | 15 | 2236D | green | .4313 | .4727 | .2209 | .3632 | 58.3 |
| $50 | 15 | 2236D | portrait | .4647 | .4216 | .2607 | .3548 | 39.2 |
| $50 | 15 | 2236D | blk letter | .4672 | .4181 | .2638 | .3542 | 13.4 |
| $50 | 18 | 1381A | lathe frt | .4746 | .4225 | .2666 | .3560 | 19.9 |
| $50 | 18 | 1381A | white | .4869 | .4256 | .2730 | .3580 | 92.9 |
| $50 | 18 | 1381A | green | .4558 | .4617 | .2390 | .3631 | 54.8 |
| $50 | 18 | 1381A | portrait | .4797 | .4236 | .2694 | .3568 | 36.2 |
| $50 | 18 | 1381A | blk letter | .4786 | .4192 | .2706 | .3556 | 12.7 |
| $20 | 25 | 9111B | lathe frt | .4712 | .4236 | .2640 | .3559 | 22.8 |
| $20 | 25 | 9111B | white | .4846 | .4276 | .2707 | .3582 | 86.1 |
| $20 | 25 | 9111B | green | .4465 | .4646 | .2325 | .3629 | 43.4 |
| $20 | 25 | 9111B | portrait | .4749 | .4234 | .2664 | .3562 | 21.7 |
| $20 | 25 | 9111B | blk letter | .4673 | .4214 | .2625 | .3550 | 15.6 |
| $20 | 27 | 4051D | lathe frt | .4710 | .4237 | .2638 | .3559 | 16.1 |
| $20 | 27 | 4051D | white | .4805 | .4287 | .2676 | .3581 | 107. |
| $20 | 27 | 4051D | green | .4316 | .4779 | .2194 | .3643 | 42.0 |
| $20 | 27 | 4051D | portrait | .4710 | .4236 | .2638 | .3559 | 21.1 |
| $20 | 27 | 4051D | blk letter | .4721 | .4199 | .2661 | .3551 | 14.3 |
| $50 | 44 | 3691H | lathe frt | .4527 | .4227 | .2527 | .3539 | 31.4 |
| $50 | 44 | 3691H | white | .4635 | .4271 | .2576 | .3560 | 142. |
| $50 | 44 | 3691H | green | .3784 | .4908 | .1861 | .3621 | 59.2 |
| $50 | 44 | 3691H | portrait | .4583 | .4244 | .2555 | .3548 | 54.8 |
| $50 | 44 | 3691H | blk letter | .4613 | .4184 | .2600 | .3537 | 14.6 |
| $50 | 45 | 0395D | lathe frt | .4579 | .4243 | .2553 | .3548 | 31.8 |
| $50 | 45 | 0395D | white | .4692 | .4265 | .2614 | .3564 | 118. |
| $50 | 45 | 0395D | green | .3971 | .4754 | .2008 | .3606 | 44.0 |
| $50 | 45 | 0395D | portrait | .4611 | .4228 | .2579 | .3547 | 42.5 |
| $50 | 45 | 0395D | blk letter | .4603 | .4213 | .2581 | .3543 | 21.6 |
| $20 | 48 | 3271C | lathe frt | .4737 | .4268 | .2641 | .3569 | 28.7 |
| $20 | 48 | 3271C | white | .4913 | .4299 | .2738 | .3594 | 81.0 |
| $20 | 48 | 3271C | green | .4441 | .4628 | .2317 | .3622 | 50.2 |
| $20 | 48 | 3271C | portrait | .4788 | .4258 | .2678 | .3572 | 22.0 |
| $20 | 48 | 3271C | blk letter | .4711 | .4246 | .2634 | .3562 | 18.9 |
| $50 | 90 | 8194A | lathe frt | .4548 | .4207 | .2548 | .3536 | 31.3 |
| $50 | 90 | 8194A | white | .4672 | .4278 | .2595 | .3565 | 124. |
| $50 | 90 | 8194A | green | .3825 | .4887 | .1889 | .3620 | 29.1 |
| $50 | 90 | 8194A | portrait | .4572 | .4219 | .2558 | .3543 | 54.5 |
| $50 | 90 | 8194A | blk letter | .4602 | .4182 | .2594 | .3535 | 23.9 |

Table 4 - Continued

| Denom | RP# | Serial# | Descrip | x | y | u | v | Lum |
|-------|-----|---------|---------|-----|-----|-----|-----|-----|
| $10 | 63 | 0324E | frt lathe | .4711 | .4242 | .2636 | .3561 | 32.9 |
| $10 | 63 | 0324E | white | .4728 | .4301 | .2621 | .3577 | 125. |
| $10 | 63 | 0324E | green | .4106 | .4762 | .2081 | .3620 | 48.3 |
| $10 | 63 | 0324E | portrait | .4686 | .4235 | .2624 | .3556 | 22.1 |
| $10 | 63 | 0324E | blk letter | .4722 | .4220 | .2653 | .3556 | 24.0 |
| $10 | 60 | 0436D | frt lathe | .4733 | .4268 | .2639 | .3569 | 20.4 |
| $10 | 60 | 0436D | white | .4835 | .4306 | .2686 | .3588 | 85.2 |
| $10 | 60 | 0436D | green | .4376 | .4803 | .2219 | .3653 | 39.4 |
| $10 | 60 | 0436D | portrait | .4752 | .4254 | .2657 | .3567 | 20.1 |
| $10 | 60 | 0436D | blk letter | .4693 | .4234 | .2628 | .3557 | 16.4 |
| $100 | 70 | 1292A | frt lathe | .4658 | .4267 | .2592 | .3561 | 49.6 |
| $100 | 70 | 1292A | white | .4693 | .4293 | .2603 | .3571 | 95.3 |
| $100 | 70 | 1292A | green | .3801 | .4984 | .1850 | .3638 | 37.7 |
| $100 | 70 | 1292A | portrait | .4639 | .4252 | .2587 | .3556 | 38.7 |
| $100 | 70 | 1292A | blk letter | .4606 | .4198 | .2589 | .3539 | 19.1 |
| $10 | 64 | 3652F | blk letter | .4584 | .4253 | .2551 | .3551 | 21.1 |
| $10 | 64 | 3752F | frt lathe | .4598 | .4256 | .2559 | .3553 | 36.0 |
| $10 | 64 | 3752F | white | .4656 | .4283 | .2584 | .3565 | 111. |
| $10 | 64 | 3752F | green | .4029 | .4830 | .2017 | .3627 | 48.7 |
| $10 | 64 | 3752F | portrait | .4581 | .4267 | .2544 | .3554 | 31.2 |
| $100 | 5 | 3807A | lathe frt | .4580 | .4238 | .2555 | .3547 | 32.0 |
| $100 | 5 | 3807A | white | .4666 | .4280 | .2591 | .3565 | 113. |
| $100 | 5 | 3807A | green | .3611 | .4987 | .1748 | .3622 | 33.3 |
| $100 | 5 | 3807A | portrait | .4579 | .4240 | .2554 | .3547 | 38.7 |
| $100 | 5 | 3807A | blk letter | .4481 | .4173 | .2520 | .3521 | 10.4 |
| $100 | 4 | 4275B | lathe frt | .4612 | .4242 | .2574 | .3551 | 59.0 |
| $100 | 4 | 4275B | white | .4627 | .4276 | .2569 | .3560 | 134. |
| $100 | 4 | 4275B | green | .3855 | .4861 | .1912 | .3618 | 47.6 |
| $100 | 4 | 4275B | portrait | .4577 | .4232 | .2556 | .3545 | 44.8 |
| $100 | 4 | 4275B | blk letter | .4639 | .4184 | .2616 | .3539 | 21.6 |
| $100 | 9 | 4967A | lathe frt | .4594 | .4275 | .2548 | .3557 | 49.5 |
| $100 | 9 | 4967A | white | .4680 | .4294 | .2594 | .3570 | 117. |
| $100 | 9 | 4967A | green | .4132 | .4667 | .2126 | .3602 | 34.2 |
| $100 | 9 | 4967A | portrait | .4598 | .4267 | .2554 | .3555 | 51.6 |
| $100 | 9 | 4967A | blk letter | .4547 | .4234 | .2536 | .3542 | 30.1 |
| $100 | 68 | 6554A | lathe frt | .4617 | .4265 | .2567 | .3557 | 37.1 |
| $100 | 68 | 6554A | white | .4727 | .4293 | .2624 | .3574 | 121. |
| $100 | 68 | 6554A | green | .3860 | .4934 | .1895 | .3633 | 41.7 |
| $100 | 68 | 6554A | portrait | .4599 | .4267 | .2555 | .3556 | 39.7 |
| $100 | 68 | 6554A | blk letter | .4637 | .4225 | .2597 | .3549 | 21.3 |
| $100 | 10 | 7868A | lathe frt | .4625 | .4218 | .2592 | .3546 | 38.1 |
| $100 | 10 | 7868A | white | .4717 | .4265 | .2629 | .3567 | 125. |
| $100 | 10 | 7868A | green | .4366 | .4634 | .2272 | .3617 | 50.6 |
| $100 | 10 | 7868A | bl & white | - | - | - | - | - |
| $100 | 10 | 7868A | portrait | .4610 | .4225 | .2580 | .3546 | 41.2 |
| $10 | 34 | 9197C | frt lathe | .4692 | .4244 | .2624 | .3559 | 26.7 |
| $10 | 34 | 9197C | white | .4876 | .4276 | .2726 | .3585 | 79.3 |
| $10 | 34 | 9197C | green | .4497 | .4606 | .2358 | .3623 | 34.7 |
| $10 | 34 | 9197C | portrait | .4749 | .4243 | .2660 | .3565 | 20.6 |

Table 4 - Continued          4-3

| Denom | RP# | Serial# | Descrip    | x     | y     | u     | v     | Lum  |
|-------|-----|---------|------------|-------|-------|-------|-------|------|
| $10   | 34  | 9197C   | blk letter | .4685 | .4215 | .2632 | .3551 | 10.6 |
| $100  | 72  | 9235A   | frt lathe  | .4625 | .4204 | .2583 | .3552 | 48.7 |
| $100  | 72  | 9235A   | white      | .4635 | .4276 | .2573 | .3561 | 122. |
| $100  | 72  | 9235A   | green      | .4160 | .4649 | .2148 | .3601 | 50.9 |
| $100  | 72  | 9235A   | portrait   | .4666 | .4240 | .2609 | .3556 | 42.3 |
| $100  | 72  | 9235A   | blk letter | .4634 | .4221 | .2597 | .3548 | 29.3 |

TABLE 5.

| Denom | Serial# | Cond | Sp | Descrip | x | y | Err | u | v | Value |
|-------|---------|------|----|---------|------|------|-----|------|------|-------|
| 100 | D01705318B | 1 | 3 | white | .4638 | .4286 | 6 | .2571 | .3564 | 8.31 |
| 100 | G14182119A | 1 | 3 | white | .4660 | .4295 | 3 | .2581 | .3568 | 8.22 |
| 100 | E01764108B | 1 | 3 | white | .4648 | .4283 | 6 | .2579 | .3564 | 8.39 |
| 100 | G03085925A | 2 | 3 | white | .4636 | .4296 | 4 | .2566 | .3566 | 8.17 |
| 100 | B02553157A | 2 | 3 | white | .4701 | .4297 | 7 | .2606 | .3573 | 7.81 |
| 100 | B32912844A | 2 | 3 | white | .4640 | .4304 | 5 | .2565 | .3568 | 7.84 |
| 100 | B05499602A | 3 | 3 | white | .4683 | .4279 | 13 | .2602 | .3567 | 7.49 |
| 100 | E14559159A | 3 | 3 | white | .4681 | .4306 | 8 | .2589 | .3573 | 7.62 |
| 100 | A14123251A | 3 | 3 | white | .4707 | .4305 | 8 | .2606 | .3575 | 7.52 |
| 50 | E10917144B | 1 | 3 | white | .4668 | .4290 | 4 | .2588 | .3568 | 8.34 |
| 50 | B37141855A | 1 | 3 | white | .4662 | .4295 | 1 | .2582 | .3568 | 8.45 |
| 50 | B25685311A | 2 | 3 | white | .4679 | .4300 | 12 | .2591 | .3571 | 7.82 |
| 50 | K05244980A | 2 | 3 | white | .4683 | .4296 | 2 | .2595 | .3571 | 8.03 |
| 50 | E05537104B | 2 | 3 | white | .4704 | .4290 | 6 | .2611 | .3571 | 7.59 |
| 50 | E12599052A | 2 | 3 | white | .4668 | .4288 | 6 | .2589 | .3567 | 8.31 |
| 50 | A08672507A | 3 | 3 | white | .4692 | .4277 | 11 | .2609 | .3567 | 8.25 |
| 50 | C00978776A | 3 | 3 | white | .4683 | .4303 | 10 | .2592 | .3572 | 7.24 |
| 50 | C07989265A | 3 | 3 | white | .4690 | .4296 | 3 | .2599 | .3571 | 7.63 |
| 20 | L37461741D | 1 | 3 | white | .4616 | .4285 | 8 | .2558 | .3562 | 8.27 |
| 20 | E79296101B | 1 | 3 | white | .4651 | .4287 | 4 | .2579 | .3565 | 8.19 |
| 20 | E43377968D | 1 | 3 | white | .4646 | .4292 | 5 | .2574 | .3566 | 8.28 |
| 20 | G91986092A | 2 | 3 | white | .4695 | .4307 | 1 | .2598 | .3575 | 8.13 |
| 20 | B33996919B | 2 | 3 | white | .4664 | .4298 | 5 | .2582 | .3569 | 7.98 |
| 20 | B12726295E | 3 | 3 | white | .4801 | .4303 | 11 | .2666 | .3584 | 7.44 |
| 20 | B40192998B | 3 | 3 | white | .4867 | .4267 | 6 | .2724 | .3582 | 6.35 |
| 20 | B13224869* | 3 | 3 | white | .4883 | .4301 | 12 | .2719 | .3592 | 6.71 |
| 10 | E04378361A | 1 | 3 | white | .4660 | .4289 | 7 | .2584 | .3567 | 8.26 |
| 10 | A06357333B | 1 | 3 | white | .4659 | .4297 | 1 | .2580 | .3569 | 8.17 |
| 10 | B33714296E | 2 | 3 | white | .4680 | .4297 | 5 | .2593 | .3571 | 7.89 |
| 10 | B82477632E | 2 | 3 | white | .4637 | .4298 | 1 | .2565 | .3567 | 7.88 |
| 10 | G15914317C | 3 | 3 | white | .4711 | .4290 | 2 | .2615 | .3572 | 7.68 |
| 10 | J14141372A | 3 | 3 | white | .4704 | .4304 | 9 | .2605 | .3575 | 7.92 |

Table 5 - (Continued)

5-2

| Denom | Serial# | Cond | Sp | Descrip | x | y | Err | u | v | Value |
|-------|---------|------|----|---------|----|----|-----|----|----|-------|
| 100 | D01705318B | 1 | 4 | green.seal | .3454 | .5190 | 6 | .1618 | .3648 | 5.11 |
| 100 | G14182119A | 1 | 4 | green.seal | .3318 | .5341 | 3 | .1518 | .3664 | 4.17 |
| 100 | E01764108B | 1 | 4 | green.seal | .3269 | .5374 | 6 | .1487 | .3666 | 4.74 |
| 100 | G03085925A | 2 | 4 | green.seal | .3521 | .5138 | 4 | .1664 | .3643 | 4.84 |
| 100 | B02553157A | 2 | 4 | green.seal | .3551 | .5072 | 7 | .1696 | .3633 | 4.63 |
| 100 | B32912844A | 2 | 4 | green.seal | .3771 | .4970 | 5 | .1837 | .3632 | 4.98 |
| 100 | B05499602A | 3 | 4 | green.seal | .4049 | .4742 | 13 | .2055 | .3610 | 4.48 |
| 100 | E14559159A | 3 | 4 | green.seal | .3432 | .5272 | 8 | .1589 | .3661 | 4.14 |
| 100 | A14123251A | 3 | 4 | green.seal | .4806 | .4713 | 8 | .2498 | .3675 | 5.29 |
| 50 | E10917144B | 1 | 4 | green.seal | .3675 | .4984 | 4 | .1783 | .3627 | 5.34 |
| 50 | B37141855A | 1 | 4 | green.seal | .3561 | .5111 | 1 | .1691 | .3642 | 4.87 |
| 50 | B25685311A | 2 | 4 | green.seal | .3879 | .4905 | 12 | .1913 | .3629 | 5.22 |
| 50 | K05244980A | 2 | 4 | green.seal | .3758 | .4979 | 2 | .1828 | .3633 | 4.85 |
| 50 | E05537104B | 2 | 4 | green.seal | .3712 | .5007 | 6 | .1796 | .3634 | 4.72 |
| 50 | E12599052A | 2 | 4 | green.seal | .3358 | .5426 | 6 | .1520 | .3683 | 3.97 |
| 50 | A08672507A | 3 | 4 | green.seal | .3612 | .5048 | 11 | .1733 | .3634 | 3.85 |
| 50 | C00978776A | 3 | 4 | green.seal | .3820 | .4909 | 10 | .1880 | .3624 | 4.74 |
| 50 | C07989265A | 3 | 4 | green.seal | .3872 | .4890 | 3 | .1914 | .3625 | 5.18 |
| 20 | L37461741D | 1 | 4 | green.seal | .3731 | .4945 | 8 | .1823 | .3624 | 5.40 |
| 20 | E79296101B | 1 | 4 | green.seal | .3579 | .5091 | 4 | .1706 | .3639 | 4.92 |
| 20 | E43377968D | 1 | 4 | green.seal | .3627 | .5013 | 5 | .1750 | .3628 | 5.21 |
| 20 | G91986092A | 2 | 4 | green.seal | .3759 | .5028 | 1 | .1816 | .3643 | 5.20 |
| 20 | B33996919B | 2 | 4 | green.seal | .3647 | .5105 | 5 | .1737 | .3648 | 5.00 |
| 20 | B12726295E | 3 | 4 | green.seal | .3982 | .4870 | 11 | .1979 | .3631 | 4.54 |
| 20 | B40192998B | 3 | 4 | green.seal | .3933 | .4914 | 6 | .1940 | .3635 | 4.47 |
| 20 | B13224869* | 3 | 4 | green.seal | .4102 | .4789 | 12 | .2070 | .3625 | 4.82 |
| 10 | E04378361A | 1 | 4 | green.seal | .3434 | .5110 | 7 | .1626 | .3630 | 4.88 |
| 10 | A06357333B | 1 | 4 | green.seal | .3586 | .5082 | 1 | .1711 | .3638 | 4.96 |
| 10 | B33714296E | 2 | 4 | green.seal | .3404 | .5225 | 5 | .1585 | .3650 | 4.27 |
| 10 | B82477632E | 2 | 4 | green.seal | .3514 | .5139 | 1 | .1661 | .3643 | 4.48 |
| 10 | G15914317C | 3 | 4 | green.seal | .3956 | .4828 | 2 | .1977 | .3620 | 5.27 |
| 10 | J14141372A | 3 | 4 | green.seal | .3683 | .5090 | 9 | .1760 | .3648 | 4.59 |

Table 5 - (Continued)

| Denom | Serial# | Cond | Spot | Descrip | x | y | Err | u | v | Value |
|-------|---------|------|------|---------|-----|-----|-----|-----|-----|-------|
| 100 | D01705318B | 1 | 8 | black.letter | .4633 | .4186 | 6 | .2611 | .3539 | 2.51 |
| 100 | G14182119A | 1 | 8 | black.letter | .4615 | .4166 | 3 | .2609 | .3532 | 2.21 |
| 100 | E01764108B | 1 | 8 | black.letter | .4629 | .4168 | 6 | .2617 | .3534 | 2.40 |
| 100 | G03085925A | 2 | 8 | black.letter | .4571 | .4207 | 4 | .2563 | .3538 | 2.29 |
| 100 | B02553157A | 2 | 8 | black.letter | .4605 | .4229 | 7 | .2575 | .3547 | 2.98 |
| 100 | B32912844A | 2 | 8 | black.letter | .4571 | .4216 | 5 | .2559 | .3540 | 2.66 |
| 100 | B05499602A | 3 | 8 | black.letter | .4548 | .4272 | 13 | .2521 | .3552 | 3.84 |
| 100 | E14559159A | 3 | 8 | black.letter | .4573 | .4234 | 8 | .2553 | .3545 | 3.03 |
| 100 | A14123251A | 3 | 8 | black.letter | .4584 | .4253 | 8 | .2551 | .3551 | 3.39 |
| 50 | E10917144B | 1 | 8 | black.letter | .4638 | .4191 | 4 | .2612 | .3541 | 3.20 |
| 50 | B37141855A | 1 | 8 | black.letter | .4618 | .4219 | 1 | .2587 | .3546 | 3.21 |
| 50 | B25685311A | 2 | 8 | black.letter | .4561 | .4271 | 12 | .2529 | .3553 | 3.68 |
| 50 | K05244980A | 2 | 8 | black.letter | .4607 | .4209 | 2 | .2585 | .3542 | 2.89 |
| 50 | E05537104B | 2 | 8 | black.letter | .4587 | .4210 | 6 | .2572 | .3540 | 2.46 |
| 50 | E12599052A | 2 | 8 | black.letter | .4597 | .4224 | 6 | .2572 | .3545 | 2.89 |
| 50 | A08672507A | 3 | 8 | black.letter | .4612 | .4209 | 11 | .2588 | .3543 | 2.66 |
| 50 | C00978776A | 3 | 8 | black.letter | .4572 | .4220 | 10 | .2558 | .3541 | 2.72 |
| 50 | C07989265A | 3 | 8 | black.letter | .4578 | .4240 | 3 | .2553 | .3547 | 2.93 |
| 20 | L37461741D | 1 | 8 | black.letter | .4654 | .4175 | 8 | .2630 | .3539 | 2.75 |
| 20 | E79296101B | 1 | 8 | black.letter | .4615 | .4214 | 4 | .2588 | .3544 | 2.90 |
| 20 | E43377968D | 1 | 8 | black.letter | .4649 | .4163 | 5 | .2632 | .3535 | 2.51 |
| 20 | G91986092A | 2 | 8 | black.letter | .4584 | .4223 | 1 | .2564 | .3543 | 3.16 |
| 20 | B33996919B | 2 | 8 | black.letter | .4568 | .4245 | 5 | .2545 | .3547 | 3.61 |
| 20 | B12726295E | 3 | 8 | black.letter | .4673 | .4258 | 11 | .2605 | .3561 | 3.52 |
| 20 | B40192998B | 3 | 8 | black.letter | .4639 | .4223 | 6 | .2599 | .3549 | 2.98 |
| 20 | B13224869* | 3 | 8 | black.letter | .4632 | .4255 | 12 | .2581 | .3556 | 3.13 |
| 10 | E04378361A | 1 | 8 | black.letter | .4613 | .4206 | 7 | .2590 | .3542 | 2.83 |
| 10 | A06357333B | 1 | 8 | black.letter | .4595 | .4183 | 1 | .2589 | .3535 | 2.88 |
| 10 | B33714296E | 2 | 8 | black.letter | .4611 | .4223 | 5 | .2581 | .3546 | 3.02 |
| 10 | B82477632E | 2 | 8 | black.letter | .4581 | .4222 | 1 | .2563 | .3543 | 2.82 |
| 10 | G15914317C | 3 | 8 | black.letter | .4559 | .4239 | 2 | .2542 | .3545 | 3.30 |
| 10 | J14141372A | 3 | 8 | black.letter | .4559 | .4251 | 9 | .2537 | .3548 | 3.14 |

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5. AUTHOR(S)

Belinda L. Collins, Suzin Mayerson and James A. Worthey

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A review of the literature on the noticeability of features of counterfeit bills, primarily British pound notes, is presented. The review points out the importance of prolonging the attention paid to a bank note as a counterfeit deterrent. Various design options are suggested. A pilot study on the noticeability of features of counterfeit US dollars is also presented. The study includes both spectroradiometeric measures of the chromaticity and luminance of a set of counterfeit bills and an identification study. In the identification study, 21 participants selected counterfeit bills from a much larger stack of genuine bills. They also listed the features they notices as they made their selection. Each participant successfully identified about 80 percent of the counterfeit bills, although only one counterfeit was identified by all participants. Features noticed included problems with the portrait appearance, lack of detail, color (both of the paper and the green seal), contrast, and feel. Participants also made many errors with genuine bills, although they noted fewer features and often mentioned printing press defects.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

attention; chromaticity; counterfeit bills, counterfeit deterrent; identification; luminance; spectroradiometric measures

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