

## Impact case study (REF3)

<b>Institution:</b> University of Birmingham		
<b>Unit of Assessment:</b> 4 – Psychology, Psychiatry and Neuroscience		
<b>Title of case study:</b> Enhancing the banknote security of 5 major currencies through the application of perception science		
<b>Period when the underpinning research was undertaken:</b> 2012 - 2020		
<b>Details of staff conducting the underpinning research from the submitting unit:</b>		
<b>Name(s):</b>	<b>Role(s) (e.g. job title):</b>	<b>Period(s) employed by submitting HEI:</b>
Professor Jane Raymond	Professor of Visual Cognition	2012-2020
<b>Period when the claimed impact occurred:</b> January 2014 – December 2020		
<b>Is this case study continued from a case study submitted in 2014?</b> No		
<b>1. Summary of the impact</b>		
<p><b>Global economic losses</b> from counterfeiting <b>have been mitigated</b> through University of Birmingham (UoB) engagement with central banks and the International Banknote Designers Association (representing the banknote community across 70 countries). This has led to <b>significant innovation and commercial impact in banknote production</b> as well as <b>new professional standards</b> for user testing. Banknote design and production now recognises that intaglio printing and 3D stereo visual cues are most readily identified by consumers, the prime detectors of fraud. Decisions on design underpinned by our research are now being made by central banks serving England, Europe, Australia, Canada and USA.</p>		
<b>2. Underpinning research</b>		
<p>There are approx. 700 billion banknotes in worldwide circulation. In the UK alone, 3.8 billion notes were circulated in 2019, contributing to the 11 billion payments made using cash that year (Bank of England banknote statistics). Banknotes are designed to resist counterfeit threats and are constantly evolving to embrace the latest technological advances. The general public are actually the dominant identifiers of counterfeits when they make cash transactions. However, as they are also financially harmed when a counterfeit note is unwittingly accepted, making banknotes more secure is therefore a critical public responsibility of central banks. It is also crucial for national economic security.</p> <p>Raymond's research has advanced psychological understanding of how humans identify, authenticate, and evaluate complex objects, especially banknotes. Her team's <b>key research findings</b> are:</p>		
<p><b>KF1: New technological advances have an important role to play in improving banknote security.</b> Raymond has conducted a series of studies on banknote authentication to assess the role of specific design elements for document security [R1–R5]. The work has shown how print quality (e.g., raised ink in high security intaglio printing) [R2] and 3D stereo visual cues [R3] can greatly facilitate counterfeit detection. These methods have been developed in direct collaboration with industry stakeholders (including 5 central banks, a major banknote manufacturing company and the International Banknote Designers Association). <i>Crucially, they represent a change of thinking in the industry from hard-to-mimic print features to simpler, rapidly accessible cues to aid the consumer in counterfeit detection.</i></p>		
<p><b>KF2: Perception science can be applied successfully for evaluating banknote security.</b> By adapting methods from her research on visual perception, Raymond has developed a novel approach to assess banknote authenticity and gauge consumer response to technological</p>		

changes in banknote design. The work was based around a 2-stage model [introduced in R3] wherein counterfeit detection first involves a rapid ‘gut feel’ sense of suspicion, followed by slow conscious scrutiny of fine details. This model was tested and supported in subsequent research [R3–R5] and has helped clarify the sequential uptake of different sensory cues during object authentication. It is helping the industry focus on development of a wider range of user-appropriate sensory cues.

**KF3: Eye movement data provide novel insights into how consumers spot counterfeit banknotes.** Raymond’s study [R1] used eye movement monitoring to demonstrate that initial eye movements predict authentication performance, and that a tendency existed to deploy strategic fixation toward security features. Importantly, this *improves with experience, and counterfeited features attract prolonged fixations*. Raymond has also provided insights into where in the brain the processes occur that enable counterfeit detection. This has been demonstrated to be rapid [R3, R4], with the group conducting the first electrophysiological study showing early processing of counterfeit, even in the absence of conscious counterfeit identification information [R5].

### 3. References to the research

- [R1] Raymond, J. E., & Jones, S. P. (2019). Strategic eye movements are used to support object authentication. *Scientific Reports*, 9: 2424. DOI: 10.1038/s41598-019-38824-z.
- [R2] Raymond, J. E., Jones, S. P., & Dodgson, D. B. (2017). The importance of *intaglio* in the authentication of banknotes by the general public.  
A research report for International Banknote Designers Association. A paper based on the study was presented to over 800 experts at the prestigious 2017 Currency Conference. It was also summarised in the “IBDA Insight” magazine, vol. 13, 2017: pp. 51–52 and a conference leaflet.
- [R3] Raymond, J. E., Dodgson, D. B., & Pearson, N. (2020). 3-D micro-optics enable fast banknote authentication by non-expert users. *Proceedings of Optical Document Security III*, 2020.
- [R4] Dodgson, D. B., & Raymond, J. E. (2018). *Counterfeit Sensitivity when Viewing Time is Very Brief*.  
A confidential (part redacted) research report produced for the Banks of Canada and England, the Reserve Bank of Australia and the US Federal Reserve.
- [R5] Dodgson, D. B., & Raymond, J. E. (2019). *Neural Markers of Counterfeit Detection: An ERP Study*  
A confidential (part redacted) research report submitted to funder (Bank of Canada).

### 4. Details of the impact

#### Impacts on economies across the world by transforming the strategy of central banks for banknote design

Based on KF1 and KF2, **new technologies and processes have been adopted** by central banks across the world, which will result in **significant mitigation of future losses** due to counterfeit operations. Raymond’s impact is 2-fold, highlighting both the need to design banknotes differently and providing the approaches to assess the effectiveness of changes.

In a high-profile example, the Bank of England (BoE) has used KF2 to change its procedures to support selection of security features for the next generation banknotes. BoE’s enhanced perception testing now includes Raymond’s refined behavioural tests and eye movement recordings. A senior manager from the BoE has stated:

[Raymond's] work has changed the process whereby we finalise the design for our next generation of banknotes including the new polymer series [...]. Perception testing, using methodologies developed by Professor Raymond in collaboration with the Bank have now become an integral part of our security feature assessment and selection process for all new banknotes. [S1]

The BoE are part of the Four Nations Consortium of central banks who have worked together to fund, and put into practice, Raymond's research into banknote design features (in particular, KF2). This is confirmed in a testimonial from the US Federal Reserve who states that:

Raymond's work has influenced us to further engage actively with research on perception science [...] we invested funds for research together with the Bank of Canada, the Bank of England and the Reserve Bank of Australia [...] the findings] are now influencing our internal and interagency discussions with regard to the print design of our new family of notes. [S2]

Similarly, the Reserve Bank of Australia attests that:

[Raymond's] research has provided empirical data that supports our approach to setting quality standards for our banknotes, both newly printed and circulating. [S3]

A further demonstrable collaboration with the European Central Bank (ECB) has directly influenced and validated internal practices (KF1 and KF2). The Head of Currency Development Division at ECB stated:

[Raymond's] input has contributed substantially to us being able to better assess security features [...] and develop euro banknotes which are more difficult to counterfeit and easier to authenticate. [S4]

#### Informing best practice in banknote production

The global industry producing banknotes for central banks is dominated by materials science agendas which had previously largely failed to consider sensory and cognitive limitations of human users. This has improved following a **change to professional standards, influenced by Raymond's research**, to include perception science (KF3) in improved technical standards.

This **change in best practice** was initiated by the International Banknote Designers Association (IBDA: the foremost professional association representing 70 countries, 11 major companies, 250 designers), who **set new professional standards** for user testing in design processes, based on Raymond's research (KF2 and KF3). Raymond's long-standing collaboration with the IBDA is evidenced by IBDA research funding, her chairing of two IBDA Working Groups (Perception, Public Education) and the authoring of 5 IBDA insight publications between 2012 and 2020. The President of the IBDA said:

Raymond has convinced decision-makers on the value of executing perception studies as an integral part of their design process. [S5]

Raymond has also contributed to **professional development** by providing workshops on perception science for the IBDA as well as the US Federal Reserve Bank and Swedish, Danish and Norwegian central banks. Broader reach across the industry was achieved through 6 presentations to primo banknote conferences (200–1000 attendees) between 2015 and 2020. The far-reaching impact of Raymond's research and the inclusion of perception science as **best practice** banknote design is acknowledged in central banks across the world. For example, a Senior Manager of the Bank of England's Banknote Research and Innovation, Notes Directorate, confirmed:

The Bank, and the industry in general, has thus come to realise that understanding how the public perceives authentic banknotes is a critical component of developing and designing secure banknotes. [...] her research [has] played a critical and influential role on the development of our thinking on this point. [S1]

Similarly, the Director of Product Placement at the Bank of Canada, attests that:

her work on the perception of bank notes has continued to influence the industry significantly [... Raymond's] reputation in the field and quality of her work have shined in numerous, prestigious Bank note conferences. [S6]

This influence has led to **changes in production** of banknotes. Crane Currency is a leading global banknote services provider working with over 50 central banks. Their Marketing Director stated:

Raymond's published and technical reports have had a significant impact in our organization at a number of levels including the feature development and design teams [...]. As a result [of KF2], we have begun conducting perception studies as part of our procedures for development of our new, technologically advanced security features. [S7]

#### Impacts on commerce by the creation of a new business based on perception testing

**Innovation and entrepreneurial activity**, also underpinned by KF2, has led to the development of new services provided by Secure Perception Research Ltd [S8], a niche research company specialised in secure document perception testing. Raymond's novel methods have influenced company practice and led to innovation in service provision, enabling it to attract 11 major clients from 7 countries, to achieve sustained profitability and create 5 jobs over the last 4 years. The company now provides perception science testing of currency designs for two central banks and 5 global banknote industry companies.

### 5. Sources to corroborate the impact

[S1–6] Central banks are reluctant to publish any details of their banknote design criteria, for obvious reasons. The corroboration of the impact rests on testimonials from senior spokespersons in the relevant banks and industry.

[S1] Testimonial from Senior Manager, Banknote Research and Innovation, Notes Directorate, Bank of England.

The signee has been Senior Manager of Banknote Research and Innovation at BoE for over 10 years and has overseen the transition from paper to polymer.

[S2] Testimonial from Advisor to the Cash Program, Federal Reserve Bank, USA, Operations and Payment Systems.

The Federal Reserve Bank are currently considering the first significant banknote redesign since the 1920s and are keen to engage in perception science advances in the process.

[S3] Testimonial from Head of the Note Issue Department, Reserve Bank of Australia.

The Reserve Bank of Australia partners with Bank of England on research activities on a regular basis.

[S4] Testimonial signed by the Head of Currency Development Division and by the Principal Research and Development Expert of the European Central Bank (ECB).

The Principal R&D Expert developed internal perception testing labs at ECB, consulting Raymond frequently during this process.

[S5] Report from the President of the International Banknote Designers Association (IBDA).

The President of IBDA has worked in the banknote industry for 20 years and has significant oversight of the entire banknote sector, including central banks and industrial players.

[S6] Testimonial from Director, Product Placement, Bank of Canada.

The signee is the Director of the Product Placement Team within the Currency Department of the Bank. The Bank of Canada is a known leader in banknote innovation.

**[S7]** Testimonial from Corporate Marketing Director, Crane Currency, Inc.

The signee has significant oversight of G10 and developing countries' central bank needs and provides details of the impact of Raymond's research on their processes, design and security decisions, and communications with clients.

**[S8]** <http://www.secureperceptionresearch.com/index.html> - Secure Perception Research Ltd is a registered UK company that specialises in perceptual testing for document security, bank notes and high value brands; Raymond is the Director of the company.