Institution: Liverpool Hope University

Unit of Assessment: A4: Psychology, Psychiatry and Neuroscience

Title of case study:
Improving clinical diagnosis of deficits in colour vision using age-matched normative data

Period when the underpinning research was undertaken: 2014-2019

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Galina Paramei	Professor of Psychology	October 2007–currently

Period when the claimed impact occurred: 2014-July 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact (indicative maximum 100 words)

Paramei's research exploring age-related changes in colour discrimination has informed clinical practice of colour vision diagnostics in eye hospitals and community centres internationally. Paramei's important research advanced basic scientific understanding of the effects of ageing on healthy individuals' colour vision across eight separate decades. The data, generated using the globally-employed Cambridge Colour Test (CCT), provide a first ever life-decade normative point of comparison for use in clinical diagnoses across the lifespan beyond infancy. Paramei's normative data have been widely used to inform ophthalmologists' examination, diagnosis and treatment of patients with eye conditions manifested by acquired colour vision impairment.

2. Underpinning research (indicative maximum 500 words)

Colour vision impairment is an important symptom in a number of serious health conditions ranging from eye pathologies (e.g., glaucoma) and systemic diseases (e.g., diabetes) to psychiatric conditions (e.g., schizophrenia and bipolar disorder) and addictions (e.g., tobacco addiction). Therefore it is critically important to be able to accurately determine the presence of colour vision impairments in an individual and to specify its type and degree. For assessing eye pathologies, previously an individual's colour vision was compared against normative data gathered using the standard Cambridge Colour Test (CCT: a rapid computerised method of colour vision diagnostics used worldwide (https://doi.org/10.6084/m9.figshare.11440791.v3)). However, colour vision is known to change over the lifespan in significant and important ways potentially compromising clinical decisions about the presence of colour vision impairment in age groups beyond the young.

In her research programme [3.1, 3.2, 3.3, 3.4], Paramei set out to achieve the goal of establishing normative data from a large sample (> 290) of healthy individuals from 10 to 88 years of age using the CCT. It was important to exclude all individuals with colour abnormalities in order to ensure the data was composed only of normal trichromatic individuals. In achieving this goal, Paramei has, for the first time, provided a means of making accurate clinical assessments of colour vision for younger-aged, middle-aged and older patients with eye and systemic diseases affecting colour vision. The ability to do so allows clinicians to disentangle the effects of eye and systemic diseases from those associated with typical aging.

Beyond the important goal of establishing normative data for colour vision changes across the lifespan, Paramei's findings provided significant new insights into the way colour vision varies over the lifespan [3.3]. One new finding was a two-phase lifespan change in colour vision. The first phase is defined by initial refinement in adolescence before colour vision peaks between 20-30 years of age. The second phase is defined by a gradual decline with an acceleration of colour vision loss after 60 years of age, and again in the 70s and 80s.

A second new finding came from an analysis of reproducibility measures of the CCT – its repeatability (stability of individual observer's measurements over time) and reliability (discriminative power in diagnosing the type and degree of colour vision abnormality) [3.4]. Paramei's findings indicated high CCT repeatability across findings taken in different sessions (referred to as the coefficient of repeatability). It is critically important in clinical practice in measuring change over time, as might be found when a patient's colour vision changes (for the better or worse). Additionally, the reliability of colour vision measurements provides high confidence to clinicians in the discriminative power of diagnosing the type and degree of colour vision abnormality, when classifying colour vision for an individual suspected of having a colour vision deficit.

3. References to the research (indicative maximum of six references)

3.1 Paramei, G.V. (2012). Color discrimination across four life decades assessed by the Cambridge Colour Test. *Journal of the Optical Society of America A*, *29*(2), A290-A297.

3.2 Paramei, G.V., & Oakley, B. (2013). Chromatic discrimination across the lifespan assessed by the Cambridge Colour Test. In L. MacDonald, S. Westland, & S. Wuerger (Eds.), *AIC Colour 2013. 12th Congress of the International Colour Association. Proceedings* (Vol. 2, pp.615-618), 8-12 July 2013, Newcastle, UK. The Colour Group (Great Britain) & International Colour Association.

3.3 Paramei, G.V., & Oakley, B. (2014). Variation of chromatic discrimination across the lifespan. *Journal of the Optical Society of America A*, *31*(4), A375-A384.

3.4 Fernandes, T.P., Santos, N.A., & Paramei, G.V. (2020). Cambridge Colour Test: Reproducibility in normal trichromats. *Journal of the Optical Society of America A, 37*(4), A70-A80.

Research grants awarded to Paramei:

3.G1 RES01400 and REF1011/20, August 2010–July 2012, "Chromatic discrimination across the lifespan". £10,500. Liverpool Hope University.

3.G2 Fellowship for alumni of the Alexander von Humboldt Foundation for research visits to Germany, October 2019, "Clinical application of the CCT normative data". £1,591 (€1,890). Alexander von Humboldt Foundation (Germany).

4. Details of the impact (indicative maximum 750 words)

The route to impact for Paramei's work required firstly the adoption and endorsement of her normative data by Cambridge Research Systems Ltd (manufacturers of the CCT), and secondly the demonstration and validation of the clinical utility of the normative data. Impact for patient benefit followed both these steps being achieved.

Paramei's normative data for colour perception across the lifespan has been integrated into the guidance references offered to clinicians using the CCT by Cambridge Research Systems Ltd.

[5.1]. This fact alone achieves impact given that the CCT is a globally used system in clinical diagnosis of colour vision.

Paramei's normative data is now routinely used in clinical studies of impairments in colour vision. In some cases, patient benefit is clearly an outcome given recruitment in studies is from patients receiving treatment. Three representative examples are from the Moorfields Eye Hospital (London, UK), the Psychological Care Centre, a Community-based Outpatient Clinic (Newark, USA), and the Federal University of Paraíba, Paraíba (Brazil). Below are quotes taken from clinicians using the normative data. While impact here relates to improvement in clinical practices, we highlight evidence of direct patient benefit where awareness was raised of the impact of continued addiction on colour vision.

> "I am very happy to confirm that we used your normative data for the Cambridge Colour Test (CCT) for healthy normal trichromats … in both [cases of hereditary pathology] and will continue to use these very useful data." (Professor Stockman, Honorary Consultant, Moorfields Eye Hospital, London (UK), 5.3 **S2**)

> "… we estimated the effect of the type of antipsychotic medication in schizophrenia patients … treated with either typical … or atypical … antipsychotics. By relating patients' post-treatment outcomes to the CCT normative data for normal trichromats, we were able to evaluate and compare efficiency of the treatment by the two drug types. In particular, treatment with atypical antipsychotics resulted in better chromatic sensitivity compared to the treatment with typical antipsychotics." (Professor Silverstein, University of Rochester Medical Center (USA), 5.4 **S3**)

> "We need to emphasize the importance of having the CCT normative data for healthy normal trichromats stratified by you for individual life decades, since prior to your publications there was no standardization of what chromatic sensitivity values could be considered "normal" or "abnormal". … we were/are now able to assess how color vision of patients … differs from that in age-matched controls. Specifically, we applied your data in our studies of … patients with type 1 bipolar disorder…, heavy smokers, … gas-station workers …" (Professor dos Santos, Federal University of Paraíba, Paraíba (Brazil), 5.5 **S4**)

> "We also undertook assessment of chromatic discrimination in heavy smokers aged 25-45 years. We found that, related to the CCT normative data for normal trichromats, these individuals have … overall color vision loss … **[They] were made aware of their impaired color vision and, as well, of further potential harm from their addiction, which is likely to occur decades later. … doubling the risk for age-related macular degeneration and accelerated lens yellowing (development of cataract).**" (Professor Silverstein, University of Rochester Medical Center (USA), 5.4 **S3**)

Having validated the utility of the normative data in clinical studies, we now present evidence that Paramei's data are now unambiguously being used for patient benefit alone. Two specific examples where Paramei's data has been used to inform clinical practice comes from Dr. Huchzermeyer, Consultant, Erlangen Eye Hospital (Germany) and Professor dos Santos, Federal University of Paraíba, Paraíba (Brazil). Below are quotes taken from these clinicians supporting patient benefits:

> *"It is my pleasure to confirm that we are using the normative data for the Cambridge Colour Test (CCT) for healthy normal trichromats of eight life decades that you published in your research articles ….in clinical practice and in clinically oriented research."* (Dr. Huchzermeyer, Consultant, Erlangen Eye Hospital (Germany), 5.2 **S1**)

"The normative data for healthy controls of individual life decades are essential in our practice as the "yardstick" to allow us to assess color vision in patients of different ages and various disease etiology. Importantly, the normative data enable us to diagnose the type and severity of patient's acquired color vision defects, which, in turn, helps to instruct us about the treatment tailored to the individual patient's condition. … the aggravating deficiency affects patients' quality of life." (Dr. Huchzermeyer, Consultant, Erlangen Eye Hospital (Germany), 5.2 **S1**)

"Patients with the following eye diseases are among those whose colour vision was tested by now in our clinic using the CCT and related to the normative values for the corresponding age decade: retinitis pigmentosa (N = 19); glaucoma (N = 30); Leber hereditary optic neuropathy (N = 4); Morbus Stargardt (N = 10)..." (Dr. Huchzermeyer, Consultant, Erlangen Eye Hospital (Germany), 5.2 **S1**)

"Since the CCT is currently broadly employed in clinical settings for color vision diagnostics, the now available CCT normative data, or "cutoffs", are particularly important in guiding clinicians in decision-making about patients' chromatic sensitivity as the biomarker of their condition. Importantly, the CCT normative values proved to be especially useful for the diagnosis of the type and severity of acquired color vision defects in clinical populations, as well as for monitoring the progression (or regression) of the disorder, which, in turn, instructed us whether the treatment tailored to the individual patient's condition was efficient." (Professor dos Santos, Federal University of Paraíba, Paraíba (Brazil), 5.5 **S4**).

"In summary, the use of the CCT normative values has helped us to improve the prognosis and treatment of individuals with certain neurodevelopmental conditions and, hence, to support improving the quality of life of patients." (Professor dos Santos, Federal University of Paraíba, Paraíba (Brazil), 5.5 **S4**).

Overall, the impact of Paramei's research is based on the importance of the detection of colour vision deficits across the lifespan as a marker of disease for patient treatment, management, and quality of life. Paramei's normative data is endorsed and disseminated by the manufacturers of a globally used clinical colour testing system. The utility of the normative data for clinical purposes having been shown in clinical studies, its use is now becoming established in multiple clinics for the diagnosis and treatment of patients with colour vision deficits.

5. Sources to corroborate the impact (indicative maximum of 10 references)

Cambridge Research Systems Ltd.

5.1 Cambridge Colour Test (webpage):

https://www.crsltd.com/tools-for-vision-science/measuring-visual-functions/cambridge-colour-test

Evidence of the impact in clinical practice

5.2 Dr. Huchzermeyer, Consultant, Erlangen Eye Hospital, Germany (evidence source **S1**)

5.3 Professor Stockman, Honorary Consultant at Moorfields Eye Hospital (London) (evidence source **S2**)

5.4 Professor Silverstein, University of Rochester Medical Center (USA) (evidence source **S3**)

5.5 Professor dos Santos, Federal University of Paraíba, Paraíba, Brazil (evidence source **S4**)