

A multifaceted approach into the effect of coloured environment on impulsivity using personality, behavioural and neurological methods.

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

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Abstract

The direct interplay between colour and impulsivity has yet to be researched despite growing interest and activity in the field. The implications of gaining a better understanding of this area helps: realise the impact of LED use in modern environments, address the lack of evidence in reported crime and impulsive psychopathologies relating to coloured light and builds an understanding of impulsivity as a testable concept. The comparison of personality, behaviour and neurological approaches were used to understand: The effect of colour on moods and personality traits associated with impulsiveness, how colour interacts with impulsive behaviours and to explore how colour alters brain activity relating to impulsivity.

Various methods were used in each approach: four self-report personality measures, two behavioural tasks and an electroencephalogram for information regarding brain activity.

Results from the personality approach indicated that participants felt more impulsive under red light. However results from behavioural and neurological approaches differed indicating that blue light caused increased bursts in a balloon analogue risk taking task and increases in frontal (F3, FZ and F3 position) beta wave activity. These both suggest an increase in impulsiveness. Faster reaction times in the blue go/no-go task condition hinted at better performance but may also be an indication of hampered behavioural inhibition. These findings are contrary to the traditional notion that long wavelength lights are stimulating and short wavelength lights are relaxing but do align with the effects observed when intrinsically photoreceptive ganglion cells are active.

It is recommended that until further empirically robust research is conducted, interventions relating to coloured environments effect on serious impulsive pathologies should not be implemented. Most prominently cases of blue light being used to reduce violent crime and suicide. The research also highlights the complexity of impulsivity, the difficulties in measuring it and the need to focus on sub-constructs in order to make accurate inferences about the effect of colour and impulsiveness in the future.

Research Image of the Year Submission



This image comprises of five pictures taken of the coloured conditions used in this PhD. Once stitched together and aligned into a single image it displays the complete test environment where participants underwent EEG (brain imaging), personality questionnaires and behavioural tasks.

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1. Research outline and purpose

1.1 Context of Work

Advancements in lighting technology

The global lighting market is predicted to grow steadily into the 2020s and beyond. A transition away from traditional light source technologies such as incandescent and halogen lamps to light emitting diodes (LED) is expected (-11% traditional, +13% LED in 2015, 84% LED market penetration by 2020; Frost & Sullivan, 2015). This advancement brings several improvements: Lifespan, energy efficiency, maintenance, health and safety, light quality and customisation. Although already popular in professional lighting markets in Europe, North America and China, LED application in residential settings is only recently starting to expand to outdoor lighting; a facet of the quickly evolving smart cities of today. The ability to manipulate the colour of light through LED technology was previously only accessible to the professional lighting industry; however, due to popularisation it is now commonplace resulting in a rise in dynamic lighting environments at home. Several products are currently on the market with Philips positioning itself to be a market leader with a wide range of hue-adjustable consumer LED products (see figure 1) available on their website (Philips, 2016a).



Figure 1: Hue Personal wireless lighting (Philips, 2016b).

Case studies

In recent years there have been a number of suggestions that blue light has an influence on behaviours relating to impulsive pathologies. These are discussed in table 1.

Table 1: Blue light case studies

| Location | Environment Change | Result | Source |
|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|---------------------------------|
| <i>Glasgow, Scotland</i> | Introduced blue street lighting to improve the city's park landscape in 2000 as part of an art installation. | Retrospectively it was observed by police that the number of violent crimes had decreased | (Review paper by Grohol, 2008). |
| <i>Nara, Japan</i> | Prefectural police set up blue streetlights in 2005. | Crime rates decreased by about 9 percent in blue-illuminated neighbourhoods | (Grohol, 2008) |
| <i>Yokohama, Japan</i> | Keihin Electric Express Railway changed eight blue lights on the ends of platforms at Gumyoji Station in response to the ongoing suicide attempts being carried out every year. | Since the blue lighting has been introduced, there have been no further suicides. | (Grohol, 2008). |
| <i>National Rail, UK</i> | A series of trials were announced in 2014 to equip selected stations with blue lights in a combined effort with a Samaritans campaign to curb the number of suicides occurring at the platform edge. | To be confirmed. | (Whipple, 2014). |

Although there is an abundance of articles which make claim to the effectiveness of blue light altering behaviour, there is very little explanation or empirical evidence of the underlying processes that may be at work. A quasi-ecological study comparing railway suicide numbers pre- and post-installation of blue light claimed that suicides decreased by 84% after the alteration (Matsubayashi, Sawada & Ueda, 2012). The authors controlled for some previously overlooked compounding variables: the number of suicides in the previous years, use of faster trains, the proximity to psychiatry hospitals. The authors had no control of the original study's validity so the claims should still be questioned. Challenges were made that these suicide prevention methods would have very limited effects and that individuals may just seek out new locations (Ichikawa, Inada & Kumeji, 2014). Experts in the field are still not convinced, "there is no research that proves that blue lights will dissuade people from killing themselves" Professor Tsuneo Suzuki (Mikkelson, 2015). There is currently uncertainty regarding any direct links between changes in coloured light and impulsive behaviours as there is no data establishing a definitive causal connection between blue streetlights and reductions in suicide or crime rates. There is, however, enough interest in this area to justify a more empirically grounded approach to investigate this link further.

Business applications

Neuro-marketing is a term coined by Ale Smidts in 2002 (Boricean, 2009) and has developed quickly as a field. Early papers made the interconnection between neuroscience, biology and decision making and the integration of these fields has offered tremendous potential to marketing applications (Shiv *et al.*, 2005). This developed into a new field 'decision neuroscience' (Levy & Glimcher, 2012) and later the specific facet 'consumer neuroscience', which is applying neuroscience principles and techniques to consumer behaviour and marketing problems (Shiv & Yoon, 2012).

It has been estimated that around 90% of people make impulse purchases (Hausman, 2000). Impulsive buying behaviour has been studied widely (d'Astous,

1990; Verplanken & Sato, 2011) and in some cases can be a precursor for compulsive buying disorder (Sun, Wu & Youn, 2004). This is a self-regulation pathology that affects 5% of the population (Claes *et al*, 2010). It has been proposed the colour of environment and or packaging may have an influence on purchasing behaviour. Claims have been made that sellers can increase apparel impulse buying by decorating their stores in a certain style or by using attractive lights and colours (Alice, 2006) and by manipulating the in-store environment stimuli to induce emotional states synonymous with increased in-store shopping behaviour (Tai & Fung, 2011).

1.2 Aims of Investigation

The aims of this investigation are:

- To assess whether there is an effect of colour on moods and personality traits associated with impulsiveness.
- To investigate the effect colour has on impulsive behaviours.
- To explore the effect of colour on brain activity related to impulsivity.
- Comparing personality, behaviour and neurological-based approaches to understand a more complete relationship between colour and impulsivity.

1.3 Overview of Studies

The personality-based approach identifies impulsive mood and personality changes for both short-term states and longer term traits through the use of self-report questionnaires. These consist of: The Barratt Impulsiveness Scale (BIS 11; trait), State Impulsivity Scale (SIS; trait), The Momentary Impulsivity Scale (MIS; state) and Assessing Mood in Daily Life (AMDL; state). This study occurs in a colour-manipulated environment under an LED RGB system. The conditions for comparison are presented

in a randomised order, D65 White (as a control), Red, Green, Blue and Yellow (test conditions).

To investigate the behavioural approach the same multi-LED system illuminated environment conditions are used but with two computer-based behavioural tasks. The Go/No-Go task involves key presses after visual cues and measures the participants' ability to inhibit a behaviour. The second task is the Balloon Analogue Risk Task, which measures risk-taking behaviour through simulated balloon pumping. Combined, these measures will identify if environmental colour manipulation changes behaviours that are precursors to impulsiveness.

The next study looks at what neurological changes occur in each of the conditions. The same illuminations and Go/ No go task are used in the behavioural approach but a 9-channel EEG is fitted over the period of the study to measure the difference in activation across brain areas and overall neurological stimulation.

Finally a comparison will be made to evaluate the relationship between each perspective.

1.3 Academic Impact

The impact of these studies will be broad and have implications in several areas:

As coloured lighting is becoming more common place in the home, cities and consumer spaces, it is important to research the effects colour has on brain activity and subsequent mood and behaviour. This study will begin to address the reported relationship of colour as a compounding variable in impulsive pathologies such as suicide, violent crime and compulsive buying. Investigating this effect within an empirical framework will identify any possible mechanisms behind the phenomena reported in the above case studies and provide the foundations for future research in this under investigated field.

1.4 Thesis Structure

Broadly this thesis will contain 5 overarching chapters: Chapter 1 establishes the research outline and purpose of the study, chapter 2 investigates the theoretical background and existing works relating to this PhD, chapter 3 discusses the methodology used in the testing phase of this work, chapter 4 runs through the results gained from the studies and finally chapter 5 discusses the results, suggests possible improvements and makes conclusions based on the data gathered.

Chapter 1: Research Outline and Purpose

Chapter 2: Background Literature

Chapter 3: Methodology

Chapter 4: Results

Chapter 5: Discussion and Conclusions

2. Background Literature

2.1 Colour Ontology

Theories of colour are fiercely debated within philosophy and there is conflict between physical and perceptual perspectives. The crux of the disagreement lies in whether colour is part of a mind-independent reality or purely a construct of cognitive processing.

Take, for instance, an individual with normal colour vision that is looking at a strawberry in daylight; the fruit has several distinctive properties. Hence it could be described as being a small pitted “red” fruit. Colour realism (Byrne & Hilbert, 1997) proposes that colours are the physical properties that an object possesses. However, just because an object ‘appears’ to have a certain property (being red) this does not necessarily mean that the object has those properties (a perceptual problem known as colour consistency).

The concept that colours are mind-independent properties of material objects separates colour realism from subjectivist theories of colour (Nathan, 1986; Westphal, 1987; Campbell, 2005; Yablo, 1995; McGinn, 1996; Watkins, 2005, 2010; Gert, 2008). Dispositional theories see colours as a quality of an object that looks coloured (Evans, 1980; McGinn, 1983; Johnston 1992). This is different to an eliminativist who believes that colours are mind-dependent properties of perceptual ‘image’ information (Russell, 1912), subjective visual field (Boghossian & Velleman, 1989), or an experience in itself (Strawson, 1989) with no external objects actually being coloured. Instead colours are perceptual experiences which ‘systematically misrepresent the true reality of independent properties’ (Chalmers, 2006).

The differences between colour realism and (reductive) physicalist theories of colour is the proposition that colours are *sui generis*. Reductive physicalists believe colours have objective surface reflectance properties (e.g. Tye, 2000; Byrne & Hilbert, 2003) or micro-physical reflectance properties (e.g. Jackson, 1996; McLaughlin, 2003)

which can be measured and quantified. Colour is not a property attributed to objects in fundamental physics; where properties such as reflectance or wavelength of light are used.

In short:

- Reductive physicalist theories see colours in purely physical terms, without explicit mention of colour properties.
- Subjective-relational theories believe that the colours of surfaces are defined in terms of the relationship between the 'perceiver' and the colour experience. This way of thinking can also be known as dispositional, subjectivist or secondary quality theories.
- Realist (primitive) theories define colours as simple properties which cannot be analysed but merely exemplified by material objects.
- Eliminativist theories believe that no external objects are coloured and it is the perceiver that artificially creates colour through a number of perceptual processes.

Colour constancy illusions are a good demonstration of subjective constancy and the complexities of these philosophical arguments. Colour constancy is a mechanism of the human colour perception system which ensures that the perceived colour of objects remain relatively constant under a variation of illuminations. The effect was described by Edwin Land (1971) who proposed the retinex theory as a potential explanation, suggesting that both the eye (retina) and the brain (cortex) are involved in the perception of colour from its physical properties.

The strawberries seen in figure 2 for instance look red, when the main illumination is in daylight (white); however, when the main illumination is artificially manipulated to blue and the strawberries are decolourised they still look 'red' (figure 3 & 4).

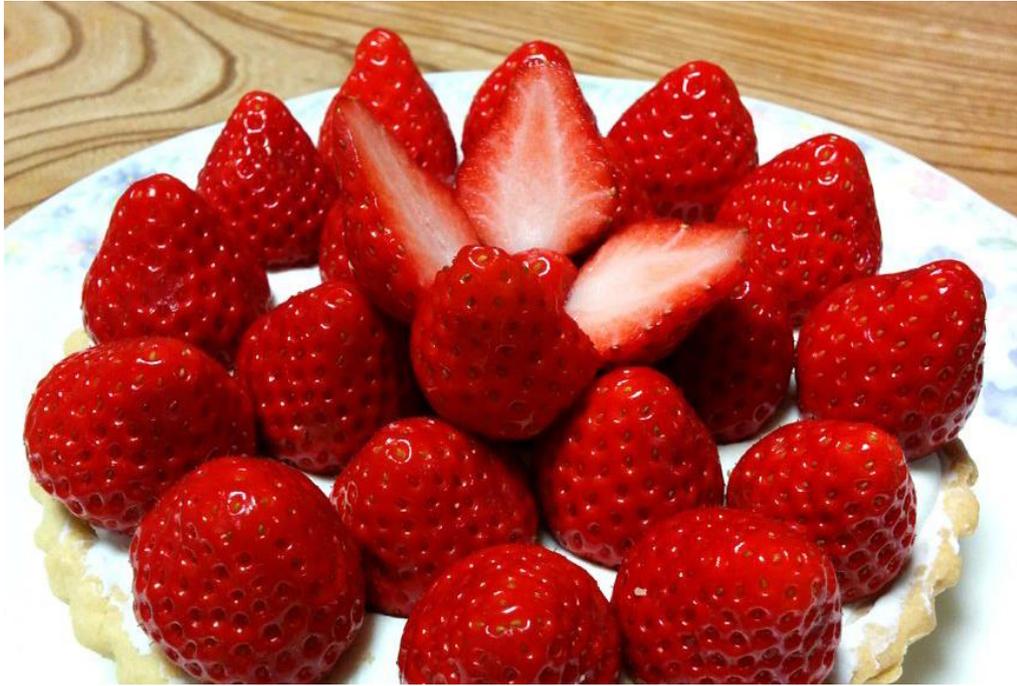


Figure 2: Strawberries under daylight (Kitaoka, 2017).



Figure 3: An example of colour constancy; Blue and grey strawberries. (Kitaoka, 2017).

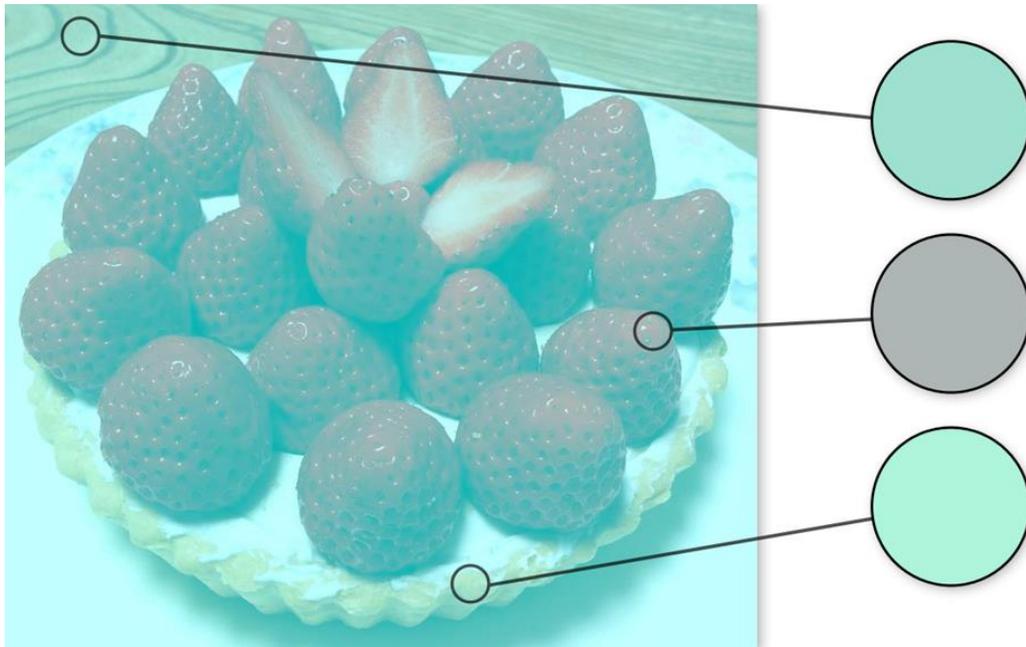


Figure 4: Colour breakdown of strawberry image (Kitaoka, 2017).

Such illusions raise important questions over philosophical considerations to make during this research. It seems that using physical measurement of colour as the primary source of information on colour, loses validity as this may vary to what the participants perceives. Therefore a distinction should be made between physical and perceptual colour. This issue is compounded by the complexity of the human image forming visual system and non-imaging forming pathways of colour perception. The physical effect of colour affects one system while the other is responsible for the creation of the perceived colour.

2.2 Colour Vision

Basic Colour vision theory and pathways.

Historically there have been two complementary phenomenological theories of colour vision - the trichromatic theory and the opponent process theory. The trichromatic, or Young-Helmholtz, theory (Young, 1802) proposed three types of

photoreceptor cells within the eye, each specialised to be sensitive to a band of light. This has been well supported by research; an early example in a fish electroretinogram (ERG) study found the combined responses from these cells allowed for the perception of colour (Svaetichin, 1956). ERG compares changes in potential between two electrodes. Using this technique different wavelengths of light were found to cause varying levels of activation in three types of photoreceptors: short-preferring (blue), middle-preferring (green), and long-preferring (red). This activation (known as S-potential) also suggested that opponency existed between the different receptor cells within the visual system.

The opponent process theory (Hering, 1872) states that colour is interpreted in an antagonistic way. Hurvich (1957) argues that the human visual system interprets information by processing signals from photoreceptor cells antagonistically. This involves the different types of cone cells; short (S), medium (M) and long (L) having overlap in light wavelength activation. It is this comparison between cones responses that allows the visual system to identify a more complex array of colours. Three proposed opponent channels exist, two of which are chromatic: red versus green, blue versus yellow, and one achromatic black versus white which detects luminance. The activation of photoreceptors in one colour of an opponent pair is antagonistic to the other colour. These antagonistic colours are not perceived together, e.g. there are no yellowish blues or greenish reds. These processes which include both retinal and post-retinal processing are now seen as being compatible as extensions of the trichromatic theory.

The concept of cone cell stimulation responses has also been reinforced by research showing the way the antagonistic receptive fields are combined, forming three predominantly independent post-receptoral responses; two chromatic pathways and a single luminance pathway (Derrington, 1984; Krauskopf, 1982). The first chromatic pathway contrasts L and M cone stimulation (red-green), while the second chromatic pathway contrasts S cone stimulation with the total stimulation of L and M cones (yellow-blue) (Shevell & Kingdom, 2008; Solomon & Lennie, 2007).

Cone spectral sensitivity

A more definite understanding has been reached on the specialized role of cone cells (see figure 5). L cone cells respond best to long wavelength light (yellow/orange hues, 564-590nm), M cones respond best to medium wavelength light (green hues 534-545nm) and S cones are stimulated the most by short wavelength light (blue hues, 420-440nm; Hunt, 2004; Wyszecki & Stiles, 1982). It has also been established that the maximum spectral sensitivity of these cells varies between daylight conditions (555 nm) and night-time (507 nm) (Gross, Blechinger & Bertram, 2008).

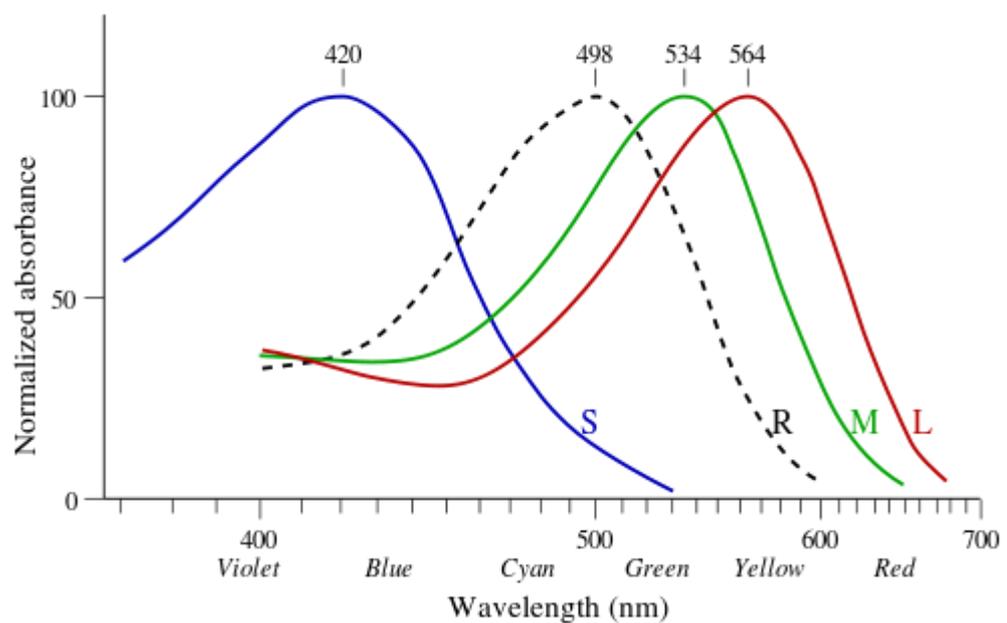


Figure 5: The spectral sensitivity of three-types of cone cells (S, M, L) and the rod cells (R, dashed line).

Metamers

Metamers are perceptually identical colours that when examined through spectral power distribution, do not match (see figure 6). It is a phenomenon resulting from the limitations of human colour vision. Spectral power distribution is the proportion of total light emitted, transmitted, or reflected by a colour sample at each visible

wavelength; which sums the total information about the light coming from the source. As the human eye contains only three colour receptors (see cone spectral sensitivity) all colours are reduced to three sensory quantities (tristimulus values). Metamerism occurs as each photoreceptor type responds to the total energy from a wide range of wavelengths. Therefore different combinations of light from across the spectra can produce an equivalent receptor response (with identical tristimulus values).

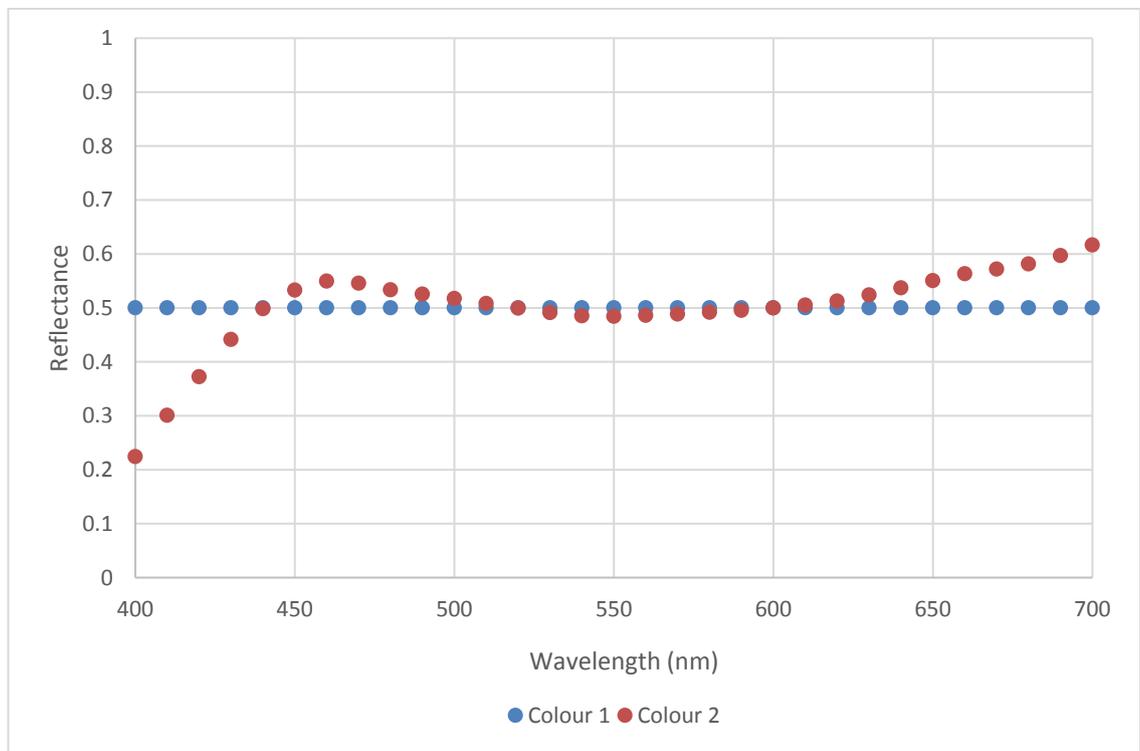


Figure 6: Spectral Distribution in a metameric colour match.

Retino-cortical pathways

The neural pathways of colour vision travel from the retina to the lateral geniculate nucleus (LGN) of the thalamus and into the visual area 1 (V1 area) (Tailby, Solomon, Dhruv & Lennie, 2008). Zeki & Marini (1998) conducted a functional magnetic resonance imaging (fMRI) study investigating three cortical stages beyond the V1. Findings showed that activation begins in V1 and travels to the visual area 4 (V4) irrespectively of natural or unnatural colouration. 'Normal' coloured objects activate

'more anterior parts of the fusiform gyrus, the hippocampus and the ventrolateral frontal cortex', in contrast abstract coloured objects 'activated the dorsolateral frontal cortex'. It was also found that there are three overarching cortical stages of colour processing: The first stage, 'detection' is involved in determining the presence and intensity of light. This process occurs in the V1 and V2 areas. The second stage is an automatic colour constancy process within the V4. The final and third stage in the inferior temporal and frontal cortex determines object colour and surface recognition. Collectively these processes make it possible for humans to perceive approximately 10 million different colours (Judd & Wyszecki, 1975) with some suggesting this can be up to an unlimited amount (Fairchild, 2010).

Intrinsically photosensitive retinal ganglion cells

In recent years a new photoreceptor has been identified, intrinsically photosensitive retinal ganglion cells (ipRGCs), the subtypes and distribution of these cells types have been discovered in animal studies (see figure 7). The ipRGCs respond slower than rods and cones through extended light exposure (Wong, Dunn & Berson, 2005). They account for <1% of retinal ganglion cells (Berson, Dunn & Takao, 2002) and are non-image-forming. They vary from those of pattern vision as they can give stable representations of ambient light intensity. Although research is on-going, a number of mechanisms controlled by these cells have been identified:

ipRGCs contribute heavily in the synchronisation of the 24-hour light/dark cycle of the circadian rhythms as well as providing length-of-day and length-of-night markers through activation levels. This information is transmitted via the retino-hypothalamic tract (RHT) directly into the suprachiasmatic nucleus of the hypothalamus (Ecker *et al.*, 2010). Melanopsin, the photopigment of ipRGCs, is activated by predominantly blue light, occurring at peak spectral sensitivity between 460 and 484 nm (Berson, 2007).

The novelty of these cells means that the exact photo-transduction mechanism is not fully understood; however, it is recognised that they respond to light by depolarizing and increasing the rate at which they fire nerve impulses. While they respond directly

to light, excitatory and inhibitory influences have been observed through rods and cones by way of synaptic connections in the retina.

It has also been found that ipRGCs contribute to the regulation of pupil size and additional neurological responses to ambient lighting conditions through the centre of pupillary control and the olivary pretectal nucleus (Ecker *et al.*, 2010). In neuropathology studies, subjects who suffer with disorders of rod and cone photoreceptors have shown to mediate light recognition through ipRGCs. Rodless and coneless humans could consciously perceive light with a powerful 481 nm stimulus. This indicates that although non image forming these receptors enable some rudimentary vision, predominantly for blue light (Zaidi, Hull & Peirson, 2007).

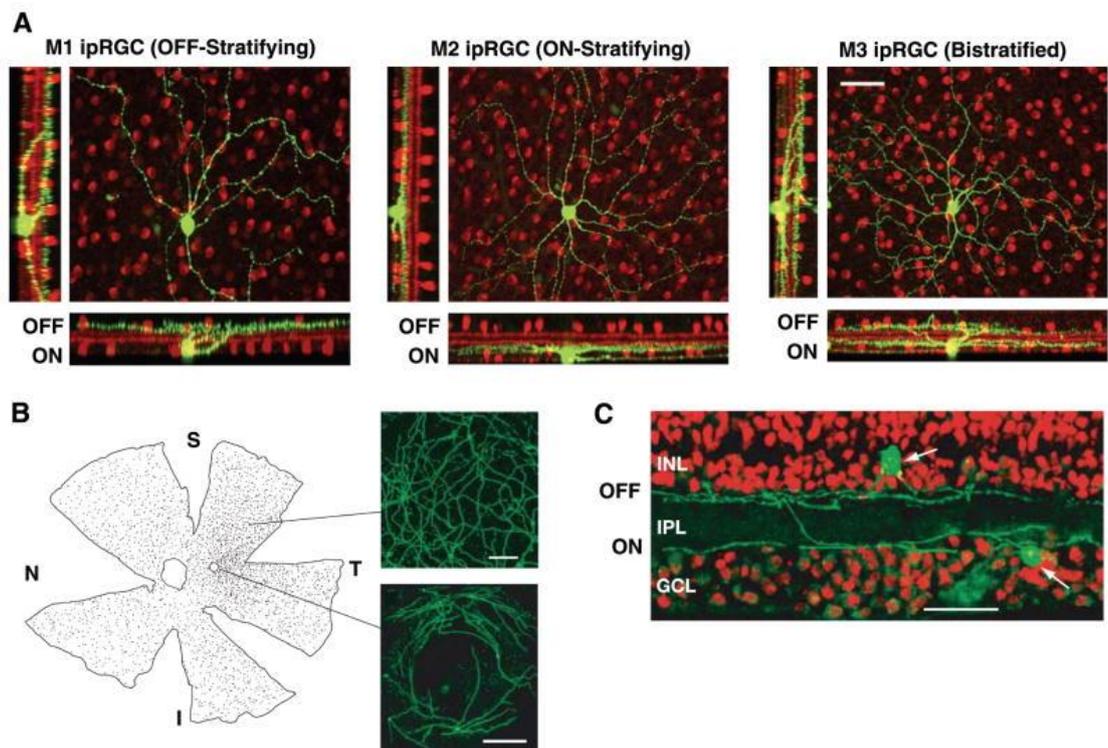


Figure 7: Morphological diversity and distribution of ipRGCs (Do & Yau, 2010). A; stacked confocal micrographs demonstrating three morphological subclasses of ipRGCs in mice. B; distribution of melanopsin-expressing retinal ganglion cells (dots) in the macaque retina. C; stacked confocal images of vertical sections through the macaque retina.

ipRGC pathways

A study using transgenic mice visualized the axons of ipRGCs and characterized which areas of the brain they project to. Dense connections were observed to the suprachiasmatic nucleus and the intergeniculate leaflet which are both intrinsic to the circadian system. There were also projections to the olivary pretectal nucleus which is responsible for mediating the pupillary light reflex (Hattar, 2006). In addition there were axonal fibers to the lateral and ventrolateral preoptic areas, which are responsible for the release of reproductive hormones from the pituitary glands. Several other areas which can be seen in figure 8 involved in a plethora of non-image forming functions.

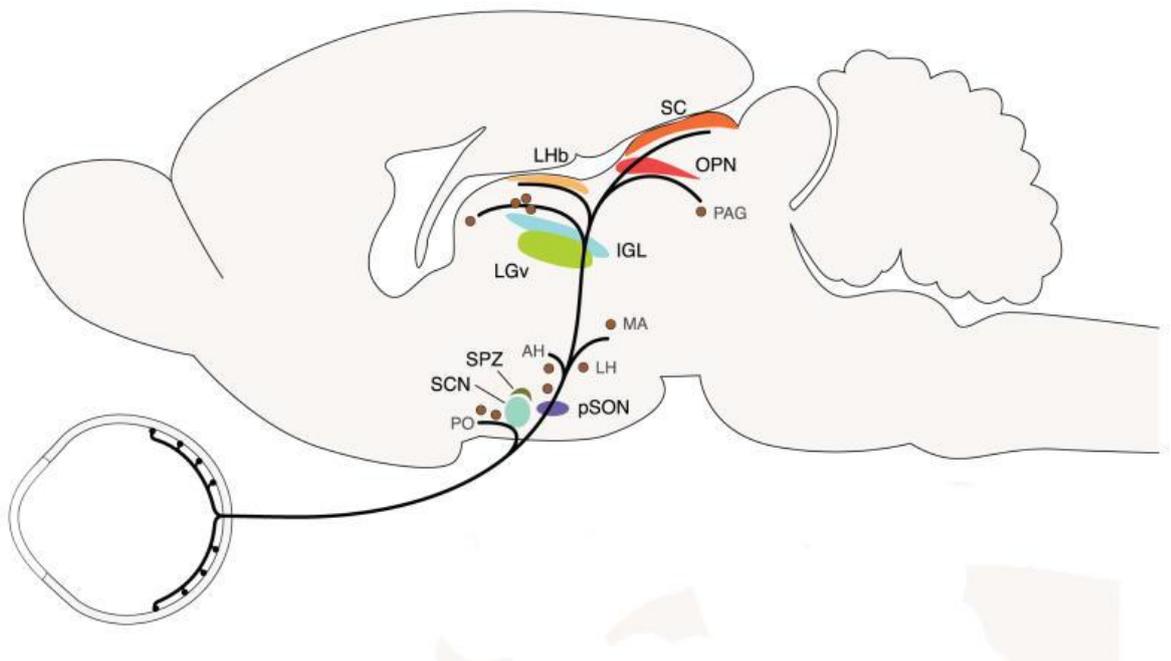


Figure 8: Brain targets of ipRGCs (Do & Yau, 2010). PO (preoptic area); SCN (suprachiasmatic nucleus); SPZ (subparaventricular zone); pSON, (peri supraoptic nucleus); AH (anterior hypothalamic nucleus); LH (lateral hypothalamus); MA (medial amygdaloid nucleus); LGv (ventral lateral geniculate nucleus); IGL (intergeniculate leaflet); BST (bed nucleus of the stria terminalis); LGd (dorsal lateral geniculate nucleus); Lhb (lateral habenula); SC (superior colliculus); OPN (olivary pretectal nucleus); PAG (periaqueductal gray).

2.3 Colorimetry

When it comes to the definition, categorisation and measurement of colour there are many approaches that can be taken. Wyszecki (1973) describes basic colorimetry as 'a tool to predict whether two lights (visual stimuli) of different spectral power distributions will match in colour for certain given conditions of observation'. This prediction is tested by determining the tristimulus values of the two visual stimuli. If the tristimulus values of a stimulus are identical to those of the other stimulus, a colour match will be observed by an average observer with normal colour vision.

The visual appearance of colour has multiple parameters: hue, colorfulness, chroma, saturation, lightness, and brightness. Colorfulness is in reference to the perceived intensity of a single color. It is the visual sensation of a more or less chromatic area in the field of view (Fairchild, 2013). Chroma is colorfulness but in relation to the brightness of a similarly illuminated area that appears to be white or highly transmitting. Saturation of a colour is a culmination of light intensity distribution across the spectrum of different wavelengths. The more a colour is saturated the 'purer' it is (high intensity of a single wavelength). A good example of this is the light emitted from a laser. Lightness, which is also known as value or tone represents the variation of perceptual brightness of a color space or colour. Brightness refers to an absolute term gained through the visual system detecting the extent a source appears to radiate or reflect light (the perception elicited by the luminance of an object)

The Munsell colour system (Munsell, 1919) encompasses three of these properties corresponding to hue, value (lightness), and chroma. This was the first system to systematically illustrate colours in a three-dimensional space (see figure 9). Munsell's system is still in wide use today but has been superseded by various colour models.

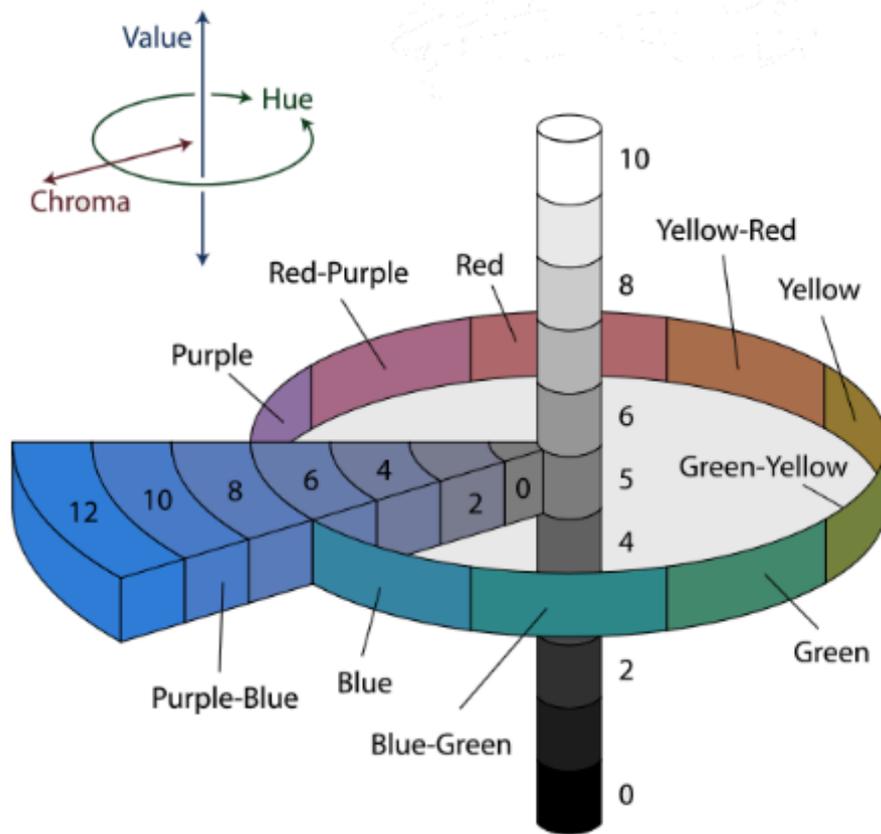


Figure 9: An example of the Munsell colour system: circle of hues at value 5 chroma 6. With 0 to 10 lightness and chromas of purple-blue (5PB).

Colour Physics

Within physics, colour is seen as electromagnetic radiation (EMR) that consists of wavelength, frequency and intensity. The famous Einstein-Planck equation is described as $E = hf$ where E is the photon energy, h is Planck's constant and f is the frequency of light (Einstein, 1905).

It is only when the wavelength is within the visible spectrum (wavelengths which humans can perceive is from 360 nm to 780 nm), it is known as visible light (colour). A light source usually emits across many different wavelengths; this is described as a source's spectrum, the distribution and intensity of energy at each wavelength. Although the spectrum determines the sensation of certain colours through the

visual system, there are many more possible spectral combinations than there are colour sensations in human vision due to the limitations of trichromatic vision.

The ‘classic’ colours contained within a rainbow’s spectrum include all colours that can be produced with a single wavelength of light within the visible range. These are therefore called pure spectral or monochromatic colours (Newton & Shapiro, 1984). These ‘pure’ colours form a continuous spectrum; however distinct colours have been linguistically separated due to culture and historical conditions. A common list identifies six main bands which include: red, orange, yellow, green, blue, and violet. Newton recognised a seventh colour, indigo which falls between blue and violet which today would be described as cyan. It is believed that indigo was the dark blue of an indigo dye that was used at the time Newton conducted this work (Waldman, 2002). The wavelengths of the pure spectral EMR can be accurately measured in air or a vacuum (see table 2). The energy of photons (EMR) is inversely proportional to the wavelength; this means that violet light, which has the shortest wavelength, has the highest energy. As wavelengths expand towards the red end of the visible region of the electromagnetic spectrum, the frequencies and energies of colours decrease. Perceptual properties of a spectral colour may change depending on its intensity and context intensity. At a lower intensity orange-yellow will appear brown, and yellow-green appears olive-green.

Table 2: Frequencies (in terahertz) and wavelengths (nm) of pure spectral colours (Bohren, 2006).

| Colour | Nanometer (nm) | Terahertz (THz) | Micrometre (μm^{-1}) | Electronvolt (eV) | Joule per mole (kJ mol^{-1}) |
|----------|----------------|-----------------|-----------------------------------|-------------------|-----------------------------------------|
| Infrared | >1000 | <300 | <1.00 | <1.24 | <120 |
| Red | 700 | 428 | 1.43 | 1.77 | 171 |
| Orange | 620 | 484 | 1.61 | 2.00 | 193 |
| Yellow | 580 | 517 | 1.72 | 2.14 | 206 |

| Colour | Nanometer (nm) | Terahertz (THz) | Micrometre (μm^{-1}) | Electronvolt (eV) | Joule per mole (kJ mol^{-1}) |
|------------------|----------------|-----------------|-----------------------------------|-------------------|-----------------------------------------|
| Green | 530 | 566 | 1.89 | 2.34 | 226 |
| Blue | 470 | 638 | 2.13 | 2.64 | 254 |
| Violet | 420 | 714 | 2.38 | 2.95 | 285 |
| Near ultraviolet | 300 | 1000 | 3.33 | 4.15 | 400 |
| Far ultraviolet | <200 | >1500 | >5.00 | >6.20 | >598 |

Object colour

Object colour is dependent on the physical properties of an object in its environment and the capabilities of the perceiver's visual system. From a physical perspective objects can be described as having coloured light leaving their surfaces. This is affected by: the spectrum of the incident illumination, the reflectance properties of the object surface and the angles at which the object is illuminated and where the perceiver is viewing from. In some circumstances objects do not only reflect light they transmit it, which adds an extra dynamic contributing to its colour. The process of recognising an objects colour is complicated further by the influence of contextual clues (demonstrated by figure 3 & 4; colour constancy). If these perceptual effects are omitted there are a number of generalisations that can be made about the physics of object colour.

Light arriving at an opaque surface is reflected specularly (mirror-like reflection of EMR waves), scattered (diffuse scattering of EMR), or absorbed (transforming into the internal energy of the object) when it makes contact with an object. A combination of these three processes then usually occurs (Fox, 2010). An opaque object's colour is perceived by what wavelengths of light are most weakly absorbed. If all are absorbed equally weakly then an object would appear white, if all are absorbed strongly than the object would appear black. In circumstances of inefficient reflection the colour will be tinted with colours determined by the imperfection in

the objects surface. Concerning objects that emit light either scatter the transmitted light and have translucent properties or do not and are transparent. They may also reflect and absorb certain wavelengths differentially, which tints the transmitted colour. Objects may emit light through electron excitement. This energy is generated by incandescence, chemiluminescence, fluorescence/phosphorescence or from electrical contacts (Nassau, 2001).

Brightness

There are several different ways to measure 'brightness'. EMR has physical properties characterised by radiometric units. These include the number of photons, the energy of these photons and the radiant flux. Although these units are quantifiable they have very little relation to light perception of the human visual system because they use units that assign all wavelengths equal weighting based on energy alone. Photometric units however are weighted on the sensitivity of the human eye's image-forming capabilities. This is known as the luminosity function, which is different for every wavelength. Infrared radiation has energy and thus a certain radiometric reading but causes no photoreceptive response. Illuminance is a photometric measurement of how much luminous flux is spread over a given area. The total visible light present is the luminous flux (lumens, lm). The illuminance (lux, lx) is the intensity of illumination on a surface. One lux is equal to one lumen per square metre, $1 \text{ lx} = 1 \text{ lm/m}^2$ while the corresponding radiometric unit, measuring irradiance, is one watt per square metre, $1 \text{ lx} = 1 \text{ W/m}^2$.

The luminosity function or luminous efficiency function was created to describe the average spectral sensitivity of the human visual perception of brightness. It was formed using the subjective judgements of participants in a study comparing coloured lights by the Commission Internationale de l'Éclairage (CIE, 1932). This resulted in the creation of a luminosity function $y(\lambda)$ or $V(\lambda)$ which is used as a standard function to convert radiant energy into luminous energy. It is also vital as a matching function in the CIE 1931 colour space, which will be discussed shortly.

Two luminosity functions exist, one is designed for normal light levels, the photopic luminosity function, which best approximates the response of the visual system in daylight. In cases of low light the scotopic curve applies as the visual system responds differently. The CIE has standard tables listing the luminosity function from 380 nm to 780 nm at 5 nm intervals (see figure 10).

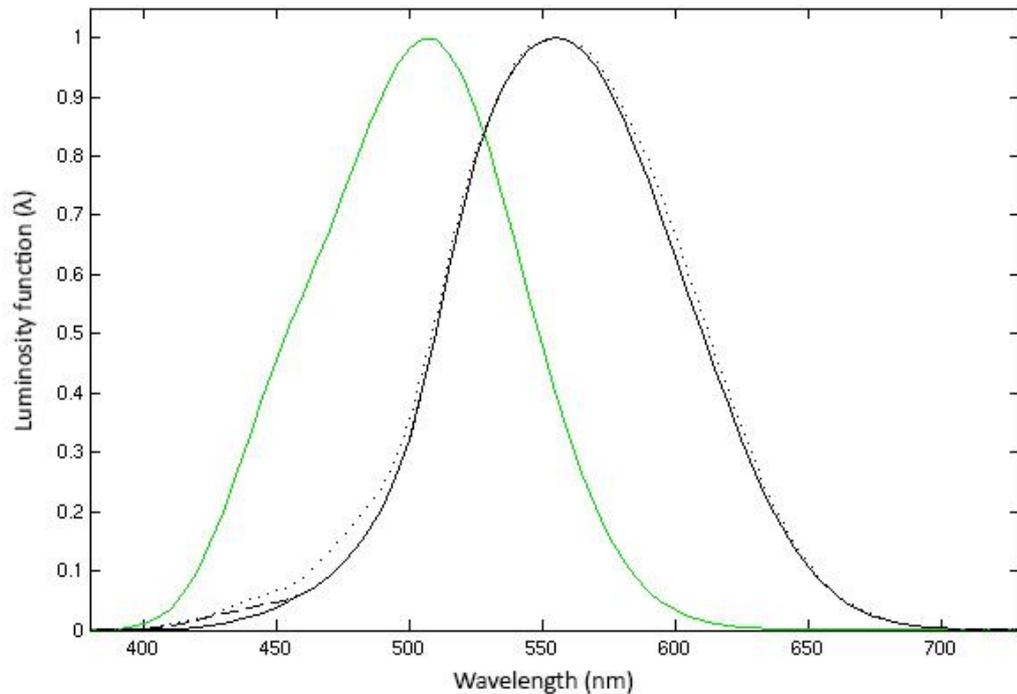


Figure 10: The Photopic (black) and scotopic (green) luminosity functions (from CIE, 1988).

Photopic includes the CIE standard (solid; CIE, 1990), the Judd–Vos (1975) modified data (dashed), and alternatively the Sharpe, Stockman, Jagla & Jägle (2005 data; dotted). The horizontal axis is wavelength in nm.

D65

The CIE Standard Illuminant D65 (Noboru & Robertson, 2005; Poynton, 2003) is part of the D series of illuminants which portray standard illumination conditions in open-air environments across different parts of the world (see figure 11: Schanda, 2007).

D65 is the corresponding code for an approximate average of midday light in Western/Northern Europe. This consists of direct as well as diffused sunlight on a clear day and is therefore named the 'daylight illuminant'. It is often used as a control lighting condition in colour research.

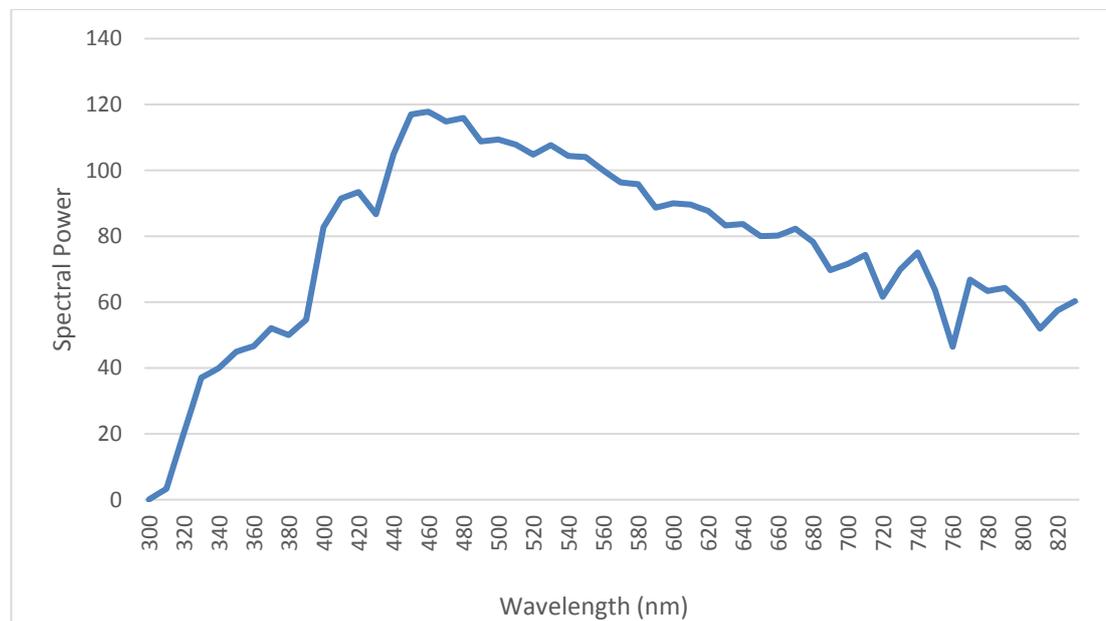


Figure 11: CIE Standard Illuminant D65 relative spectral power distribution.

2.4 Colour Models

Colour models express colours through a visual representation of a mathematical (numeric) framework. These values are then associated with descriptions that explain how to interpret the components. This process results in a 'colour space' which helps model human and computational colour.

RGB colour model.

The RGB colour model is an additive colour model in which red, green and blue light are added together in various ways (Poynton, 2003). Mixing three so-called primaries can create many colours that cover a large proportion of what colours humans can

perceive. The model is additive as the light from the three primaries is added together to create the colour's spectrum. An example of this can be seen in figure 12. This shows how mixing two of the standard three additive primary colours in equal proportions produce a secondary colour of either cyan, magenta or yellow depending on the primaries used.

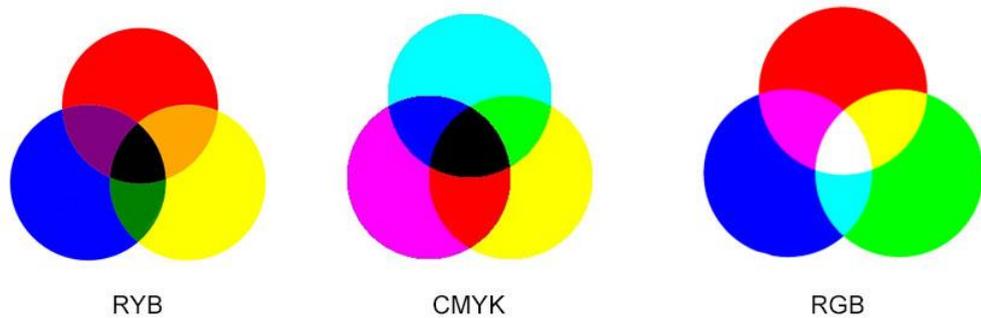


Figure 12: RYB CMYK & RGB colour models.

Electronics such as computer monitors, televisions and phones are the most common examples of additive colour mixing. Each pixel in LCD, CRT and most other types of coloured screen is composed of red, green and blue sub-pixels. The light is then blended to produce the desired colour (Boughen, 2003).

Alternative to additive primary mixing models there are subtractive colour models. These mix a limited set of colours to create a wider range by partially or completely absorbing some wavelengths of light while omitting others. The colour that a surface appears is dependent on which parts of the visible spectrum are not absorbed and therefore remain visible. Red, Yellow and Blue are the standard set of subtractive primary colours used when mixing pigments. This predated modern colour theory with its main uses being in art and art education.

This same subtractive process is used in colour printing, but with different primary colours. In this technology cyan, magenta and yellow (CMY) are typically mixed (see figure 12). Cyan absorbs red with little effect on green and blue light so the more that is applied the less red is reflected. Magenta has this same effect on green, and yellow with blue. Combinations of different amounts of the three can produce a wide range of colours with good saturation (Gatter, 2004).

Tristimulus colour space.

This three-dimensional space includes three axis: x , y , and z . XYZ is defined by the amount of three stimuli provided to the eye (the three primaries) which are represented as functions of light receptors: long-wavelength ($L(\lambda)$), medium-wavelength ($M(\lambda)$), and short-wavelength ($S(\lambda)$). As direct measurements of the cone outputs within the eye cannot be taken it is difficult to determine the three response functions accurately.

The CIE methodology used three primary light sources which were presented on half of a screen next to the test colour to be matched. The three primaries were 'pure' using only a single wavelength of light. The participants were asked to adjust the levels of the three primaries until the two halves of the screen matched. Some runs needed a negative amount of one of the primaries to achieve a match (practically, in these cases one of the primaries was added to the "test light"). This process was repeated for many test lights using multiple participants (Wright, 1928; Guild, 1932).

Results allowed for three curves to be created, one for each primary, showing the amount of the primary needed when mixed to match that of the "monochromatic" test light of a certain wavelength (wavelength λ). These colour matching functions were labelled as r , g , and b (see figure 13). The negative values of the red function were considered to be problematic so a linear transformation was used to convert R , G , and B into new functions X , Y , and Z (see figure 14). Combined, these three functions encompass the CIE standard observer (Harris & Weatherall, 1990).

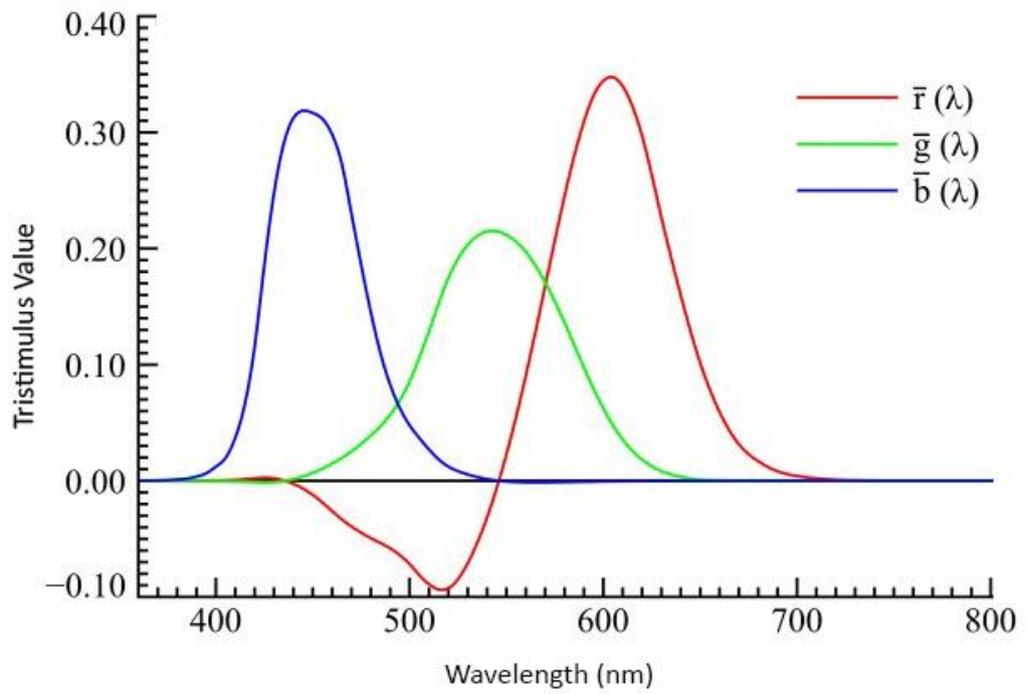


Figure 13: The CIE 1931 RGB colour matching functions.

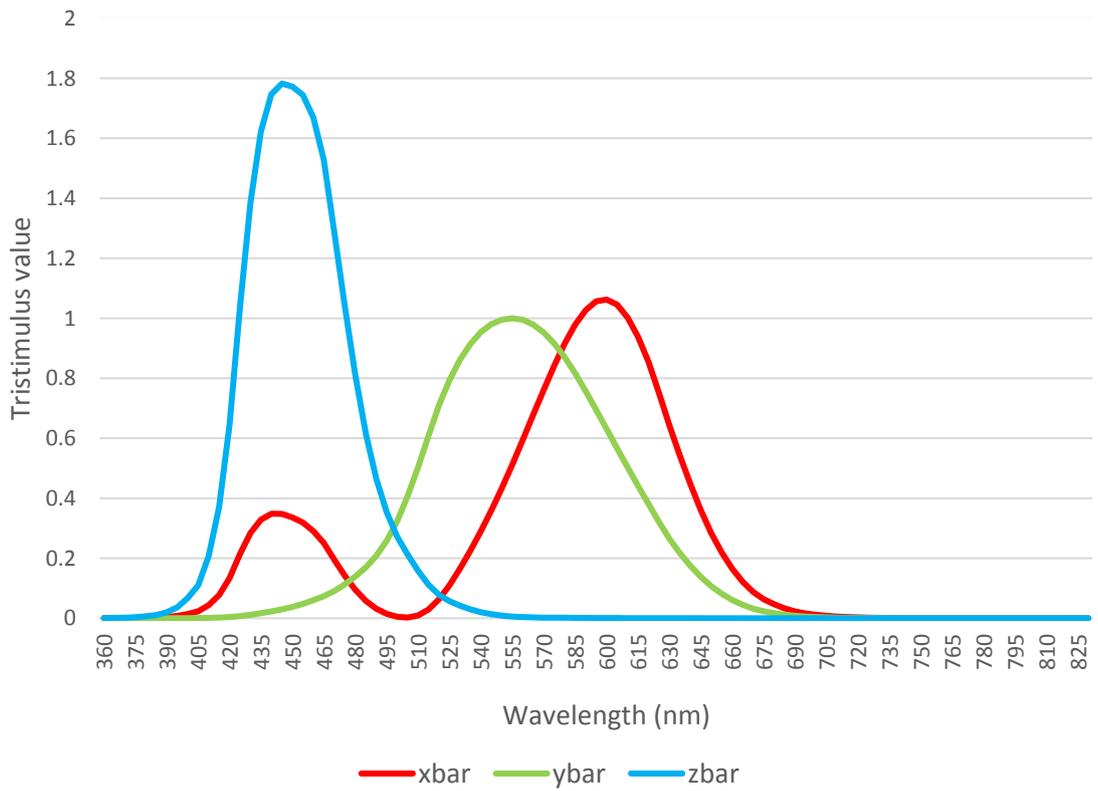


Figure 14: CIE CMFs X, Y and Z.

The CIE chromaticity model is a visual representation which converts proportions of each primary colour into rectangular co-ordinates. This visualisation of tristimulus vectors retains all information concerning the makeup of a colour. The co-ordinates of the vectors are made of the normalized tristimulus values and are called chromaticity co-ordinates. The only information lost during this process is intensity (Malacara, 2002). A curved line of spectrally pure colours surrounds the perceivable CIE gamut of colours. Within this horse-shoe-shaped diagram white falls approximately in the centre with non-spectral colours filling the space, increasing in saturation from white towards the diagram's boundary (see figure 15).

As discussed earlier, to overcome the negative values seen in the red function the underlying triangle was enlarged to include the full curve of all real mixed colours. This transformation resulted in all proportions of the primaries being positive. To make this possible the three primaries being mixed could now fall outside the gamut of perceptually viable (possible) colours. These values were therefore represented as X , Y , and Z when referring to the actual amount of each primary, and x , y , and z when in reference to their relative proportions of colour make-up.

There are a large variety of possible selections from the three theoretical primaries, to reduce this the CIE has assigned values for the Y primary (also Y_λ). These values mimic the standard luminosity curve of photoreceptors in the eye. Thus, the Y value represents the brightness or luminance of a colour (Ford & Roberts, 1998), while x and y are used as colour proportions.

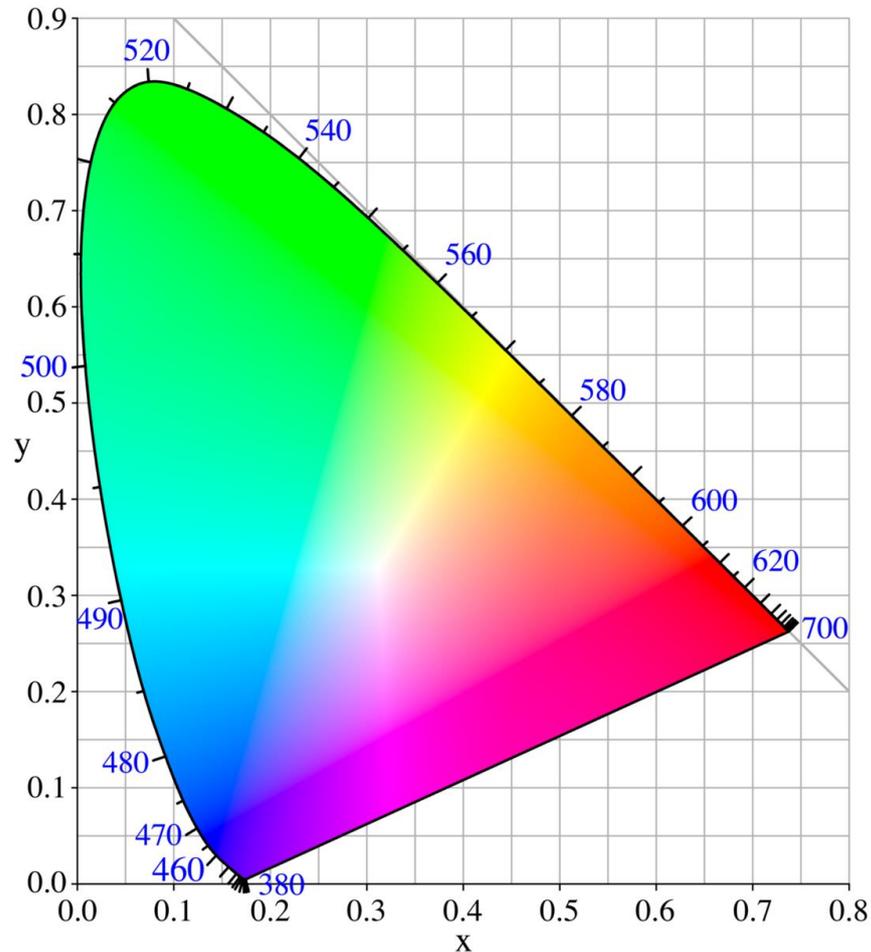


Figure 15: The CIE 1931 colour space chromaticity diagram (CIE, 1932).

Although the CIE 1931 system of colorimetry is still popular there are a number of errors. The main problem is that the colours are not uniformly represented in the space with green having a disproportionately large area. This led to the development of a new model in the 1960's (Judd & Yonemura, 1970), the CIE Luv diagram (see figure 16). The aim of this was to create a uniform colour space using linear transformations from its predecessor. Within this, colour is represented as luminance, L (identical to Y from CIE 1931) and two 'normalized' proportional values (u & v). u & v are different from x & y as they more accurately portray the perceptual difference between colours with proportional distances between colour points (Sharma & Trussel, 1997). Although generally the model is successful in normalising proportions it has been reported that it compresses yellow, brown, orange, and red colours into a disproportionately small area (Meyer & Greenberg, 1988).

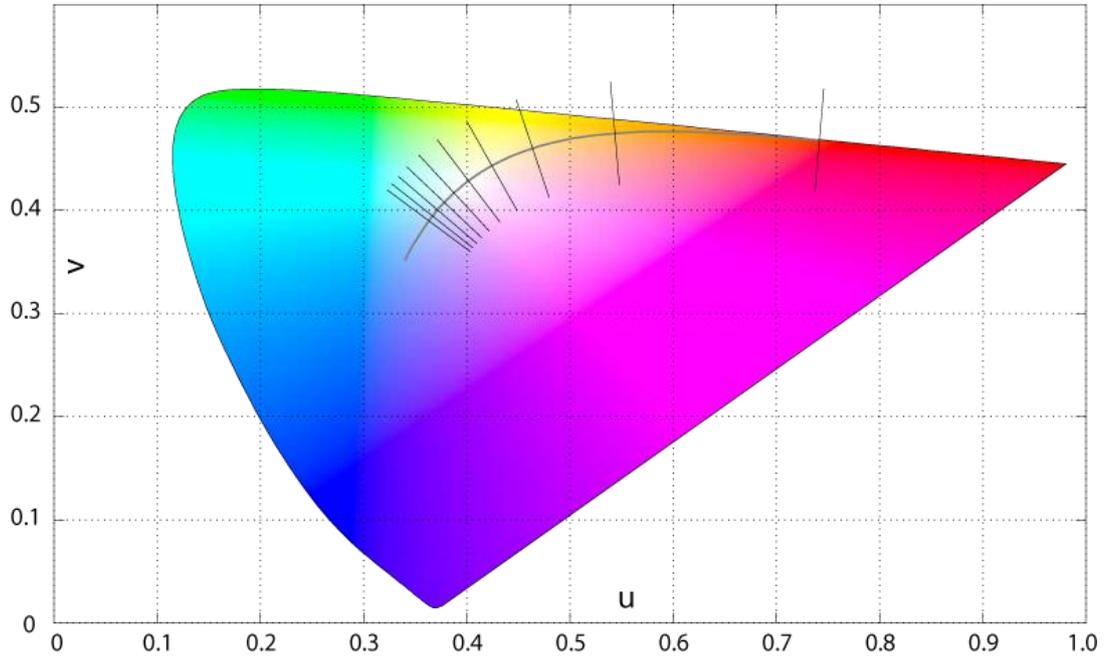


Figure 16: CIE 1960 UCS diagram, with the Planckian locus and the isotherms (1,000K to 10,000K; Judd & Yonemura, 1970).

The 1960 CIE luv (UCS) model has since been improved by non-linear transformation to the 1976 CIE $Lu'v'$ system. This refined model has more accurate euclidian distances between perceived colour differences taken from the observers. The result being more balanced spatial colour vectors in the 1976 CIE $Lu'v'$ diagram (see figure 17). Similarly to the 1960 CIE luv (UCS) model this more refined colour space has failed to replace the arguably inferior CIE 1931 colour space which is still used in many industrial applications (Yendrikhovskij, 2001).

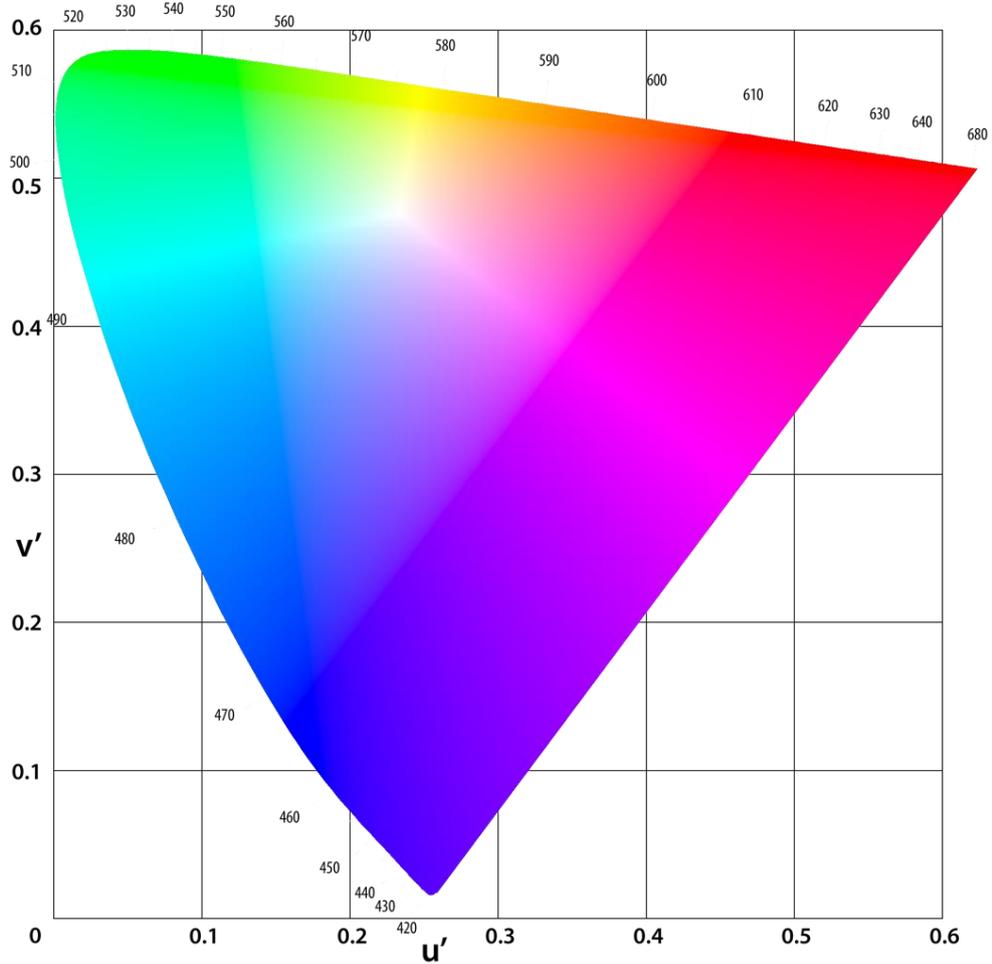


Figure 17: The CIE 1976 chromaticity diagram.

There have also been attempts to model colour in a 3-D environment. This was achieved in the CIELAB colour space, an additional non-linear transformation from the original 1931 CIE model. This has resulted in the most accurate organisation of colour in terms of numeric distances and observed difference (Hoffmann, 2009; Hunterlab, 2009)

This profiles colours into three perpendicular axes: the vertical luminance 'L' axis which extends from black (0) at the origin of the axis to white (100) and then two horizontal axes 'a' and 'b' which range from green (-) to red (+) and from blue (-) to yellow (+) respectively (see figure 18). When plotted, the perceivable human colour gamut is an irregular cone-shaped solid with its apex at the origin. This is a good demonstration of how the perceivable gamut tapers dramatically at low luminance levels and is reduced at very high luminance levels (Ford, 1998). The accuracy of this

model makes it difficult to reproduce and visualise in conventional media and visual output devices (see figure 19).

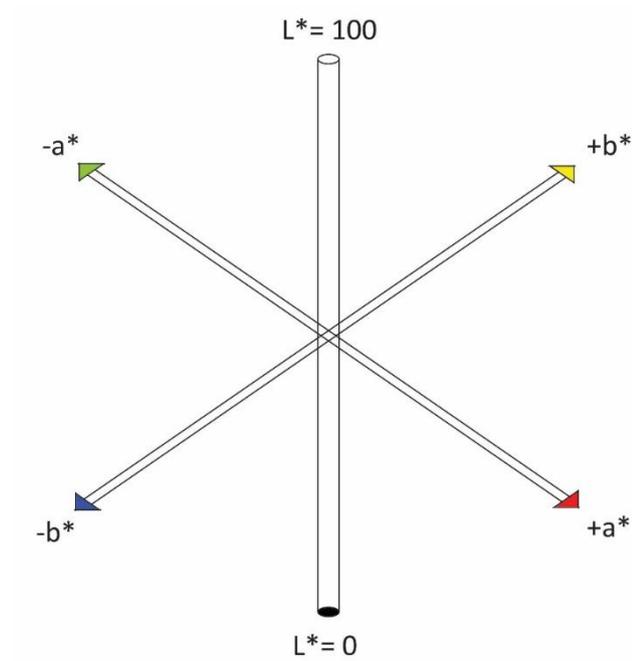


Figure 18: Diagrammatic representation of the CIELAB colour space.

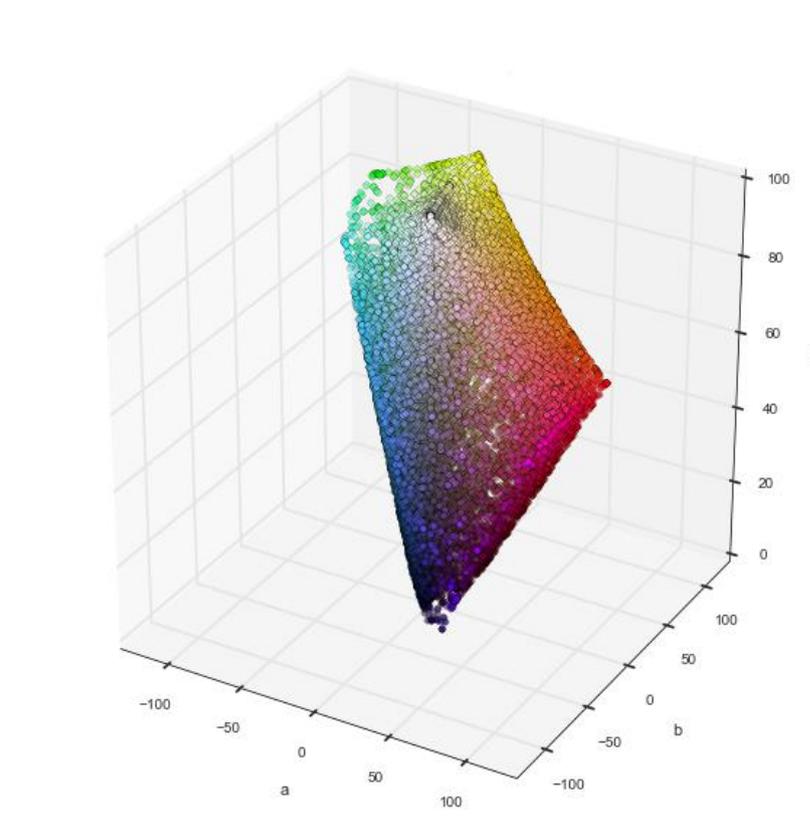


Figure 19: 3D representation of the CIELAB colours pace using mplot3d (Shin, 2017).

Colour Temperature

The colour temperature of a light source can be quantified by comparing it to the light emitted from an ideal black-body radiator at different temperatures. The spectral power distribution of a blackbody radiator is determined from its absolute, or colour temperature (Kelvin, K). Correlated colour temperature (CCT) is measuring the appearance of a light source via its chromaticity coordinates proximity to the blackbody locus (see figure 20). This is as a single number rather than the two required to specify chromaticity. Colour temperatures which are over 5000 K are referred to as 'cool' colours resembling a bluish white, whereas lower colour temperatures from 2700–3000 K are called 'warm' colours appearing yellowish/red white (Borbély, Sámson & Schanda, 2001). CCT is a quick way to communicate colour temperature although because it is represented as a single number this means that two light sources with the same CCT for example 3500 K may have different chromaticities and thus be perceptually different.

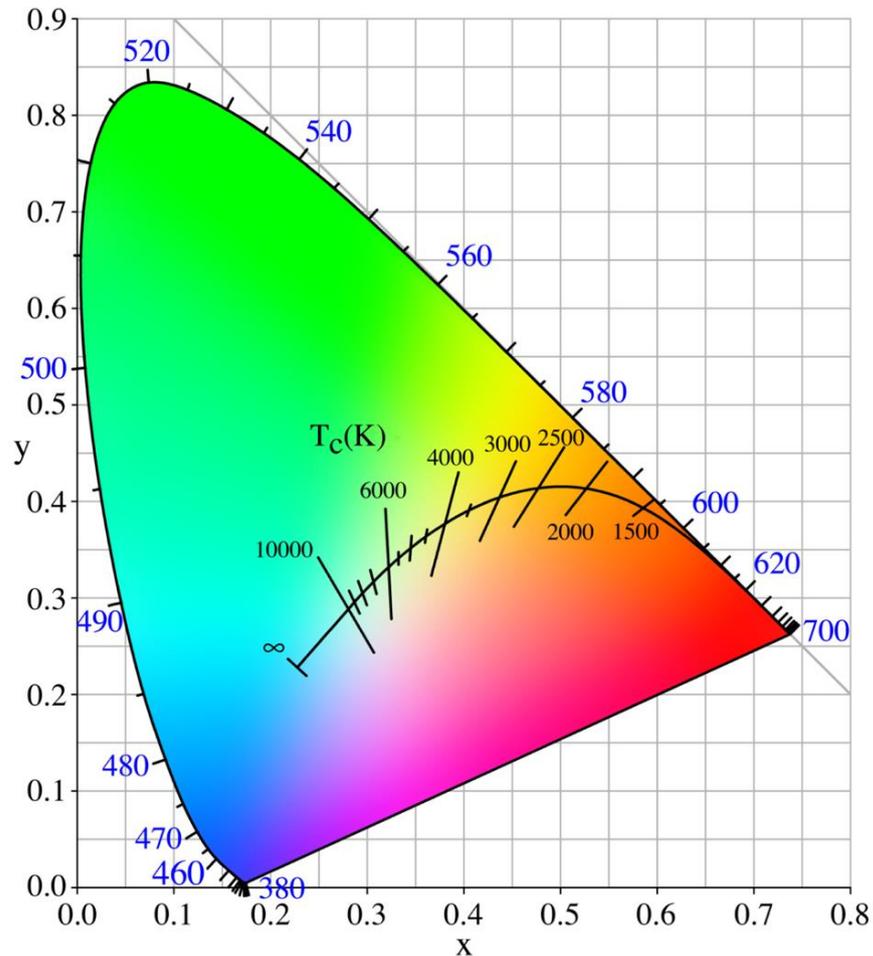


Figure 20: The CIE 1931 x,y chromaticity space with Planckian locus and lines of constant correlated colour temperature.

2.5 Defining Impulsivity and its constructs.

There are differences between disciplines of what impulsivity is deemed to be, thus several definitions exist: In medicine impulsivity is defined as “The inclined or tending to act on impulse rather than thought” or the “Motivation of actions by or resulting from impulse” (Evenden, 1999, p.349). Within the legal definition a distinction is made between controlled impulsivity “an action that is done with prior thought as a spontaneous act” and uncontrollable impulsivity (an irresistible action) such as “an impulse to commit an unlawful or criminal act which cannot be resisted or overcome by the patient because insanity or mental disease has destroyed the freedom of his will and his power of self-control and of choice as to his actions” (Black, Garner &

McDaniel, 1999). Two definitions within the psychology field state impulsivity is “a tendency to act on a whim, displaying behaviour characterized by little or no forethought, reflection, or consideration of the consequences” (VandenBos, 2007, p.112) and alternatively by Daruna & Barnes (1993, p.33) an action which is “poorly conceived, prematurely expressed, unduly risky, or inappropriate to the situation that often result in undesirable consequences,”.

A range of concepts associated with the impulsivity construct exist. Some researchers have proposed terminology through research while others have created measures of impulsivity which introduce terms relating to it. Dickman (1990) introduced two kinds of impulsivity one of which is functional and the other dysfunctional. Functional impulsivity is associated with higher levels of idea generation (Brunas-Wagstaff *et al.*, 1996), adventurousness, enthusiasm and a capacity to make fast decisions (Dickman, 1990, 1985). It is most advantageous in a scenario whereby speed outweighs a need to be accurate (Brunas-Wagstaff *et al.*, 1995). This subscale overlaps with the concept of venturesomeness which was proposed by Eysenck & Eysenck (1977) and supported by much empirical evidence discussed below. In contrast the concept of dysfunctional impulsivity, describes an “erratic disorderliness” (Jones & Paulhus, 2011, p.88). This subscale correlates with several negative behaviours such as inaccurate decision making, being distracted easily and suicide ideation (Brunas-Wagstaff *et al.*, 1995; Dickman, 1990, 1993; Dear, 2000). Interestingly dysfunctional impulsivity coincides with the concept of narrow impulsivity (Eysenck & Eysenck, 1977). Hans Eysenck also introduced the term psychoticism one of the three traits in the P-E-N model of personality (psychoticism, extraversion and neuroticism). Psychoticism is a personality profile which is commonly displayed by individuals that show aggressive tendencies and interpersonal hostility. The Eysenck I7 questionnaire (Eysenck, 1993) was constructed which identified two-factors consisting of both Impulsiveness and Venturesomeness “both Imp and Vent factors are routinely thought of by lay-persons as ‘impulsivity’. However, they are relatively independent and represent largely different behaviours” (Eysenck, 1993, p. 144). Venturesomeness and Narrow Impulsivity are both considered to contribute to individuals risk preferences (Eysenck 1985; 1993). Barratt's (1959) created the Attentional Impulsiveness Assessment Task which aimed to measure intrusive and

racing thoughts. Results displayed levels of two concepts the level of 'motor impulsiveness' which indicated a tendency to act in the moment and non-planning impulsiveness which measured the enjoyment, careful thinking and planning of the task. The BIS (Barratt Impulsiveness Scale, Barratt 1983) was created to assess the personality traits involved in impulsiveness. As the scale was revised to the BIS-11 three sub-trait concepts of impulsivity were Identified (Barratt, 1994), these included: 'ideomotor' which involves making actions without thinking. 'careful planning' A sub-trait relating to the attention (or lack of) details within a situation and finally 'coping stability' which is an orientation to thinking about the future. Coping stability shows the greatest differences between normal and psychopathological groups (Barratt, 1994).

Impulsivity has been seen by many as being multifactorial. Buss & Plomin (1975), theorised that 'impulsivity consists of more than one dimension of control' and suggested a number of factors that collectively encompass the term. Amongst these are the core concepts of inhibitory control but there also a number of other outlying aspects such as persistence, decision time, boredom and sensation seeking behaviour. All of which are statistically different to each other but still contain a relatively low correlation ($r= 0.14-0.34$). Examples of these are as follows: A lack of Inhibitory control would involve someone struggling to prevent an action with a diminished ability to wait for the outcome of a given situation. Decision time refers to quick reactions in a scenario without giving them due thought and attention. Lack of persistence is expressed though sporadic interests giving up on each one easily moving to the next. Finally Boredom/sensation seeking is when an individual would seek out new stimulating experiences and sensations but get bored of them easily.

A Systematic Method for Clinical Description and Classification of Personality Variants (Cloninger, 1987) identified three dimensions of personality which were hypothesised to have a genetic basis; novelty seeking, harm avoidance, and reward dependence. Novelty seeking was identified as "a heritable tendency toward intense exhilaration or excitement in response to novel stimuli or cues for potential rewards

or potential relief of punishment. This leads to frequent exploratory activity in pursuit of potential rewards as well as active avoidance of monotony and potential punishment” (Cloninger, 1987, p.574). Harm avoidance was defined as “a heritable tendency to respond intensely to signals of aversive stimuli, thereby learning to inhibit behaviour to avoid punishment, novelty, and frustrating non-reward” (Cloninger, 1987, p. 575). Finally Reward dependence involves “responding intensely to signals of reward (particularly verbal signals of social approval, sentiment, and succour), and to maintain or resist extinction of behaviour that has previously been associated with rewards or relief from punishment” (Cloninger, 1987, p.575). These three biologically based concepts are governed by three different brain systems each with its corresponding principle monoamine neuromodulator; dopamine, serotonin and norepinephrine. Additional research has found similar concepts relating to impulsivity. Zuckerman (2009) focused on the personality trait sensation seeking, the process of searching for are "varied, novel, complex and intense" experiences and feelings, with the willingness to "take physical, social, legal, and financial risks for the sake of such experiences." Risk is not an intrinsic element of this construct. However, it may be ignored to add additional excitement to the activity. Later research added the trait of persistence (Cloninger, Svrakic & Przybeck, 1998) which drives an individual to persevere even in a state of fatigue or frustration. Similarly to other temperament traits, which have been mentioned earlier persistence is genetically rooted meaning that it is highly heritable.

Zevon & Tellegen (1982) proposed concepts which also include ‘experience seeking’ behaviours. Danger seeking lies on one end of the spectrum with the antagonistic concept harm avoidance on the other. Danger seekers would describe themselves as enjoying adventures and activities that involve an aspect of risk. These include sports such as rock climbing, experiencing natural disasters (e.g. storm chasing) or being involved in a dangerous emergency like an armed robbery. This is in comparison to harm avoiding individuals who would participate in safer activities and experiences even if they become tedious and aggravating. The distinction is also made between control and impulsivity. This is another scale with individuals scoring highly in control showing cautious, reflective, careful, rational and level-headed properties who like to meticulously plan ahead.

Further Impulsivity concepts which relate to self-control include 'capacity for delay' an ability which is inhibited in those that display impulsive behaviour. This failure to withhold responses leads to the omission of rewards with extraverts being deficient in avoiding loss of money in a task when avoidance behaviours required the inhibition of a rewarded response (Newman *et al.*, 1985). Impulsive individuals have been identified as choosing more immediate rather than delayed gains (Rachlin, 2000) while also allowing less time to deliberate their actions (Lecrubier *et al.*, 1995). An observation which was also observed by Daruna (1993) who found impulsive individuals took action without adequate thought.

Much research has been conducted into the maladaptive properties of impulsivity. Abnormal levels are a symptom in many psychopathological disorders. Some of which include personality disorders (Barratt *et al.*, 1998), criminality (Moeller *et al.*, 2001) and substance abuse (DeWit, 2009). The fifth edition of the American Psychiatric Association's Diagnostic and statistical manual of mental disorders (DSM-5) includes a new section on disruptive, impulse-control, and conduct disorders which are characterized by abnormalities in self-control relating to some behaviours and emotions (DSM-5, 2013). There have also been several other Impulse-Control Disorders which have not elsewhere been classified which consist of; intermittent explosive disorder, pyromania, and kleptomania (DSM-5, 2013).

A number of studies which investigated the implications of self-reported impulsivity have found high impulsivity scores to be a significant predictor of negative behaviours. Comparisons were made between two groups those from control groups of individuals within the normal range of impulsivity and those with high impulsivity. Behaviours affected include; drinking to excess, the use of illicit substances, partaking in the smoking of cigarettes, alcohol dependence and stimulant misuse (Peltzer, Phaswana & Malaka, 2001; Pfefferbaum & Wood, 1994; Zuckerman & Kuhlman, 2000; Soloff, Lynch & Moss, 2000; Grau & Ortet, 1999).

A second group of studies which investigated associations between impulsivity and behaviours indicated that it plays a role in binge-eating and pathological gambling

through studying the reduced ability to resist immediate rather than delayed monetary rewards (Alessi & Petry, 2003). Reward sensitivity and rash spontaneous impulsivity are key both separately and in combination to the development and/or clinical presentation of these disorders (Dawe, Gullo & Loxton, 2004; Engle & Kane, 2004; Dawe *et al.*, 2007; Vervaet, Van Heeringen & Audenaert, 2004) Links are also made through a meta-review of the theoretical relationship between impulsivity and a number of psychological disorders which found that there were clear links to Antisocial Personality Disorder, Conduct Disorder, Attention Deficit Hyperactivity Disorder (ADHD) and Borderline Personality Disorder (Moeller *et al.*, 2001). A large non-clinical Finnish sample of 'normal' individuals found that impulsive acts are a predictor of the likelihood of initiating smoking or becoming a heavy drinker (Grano *et al.*, 2004).

There are several other behaviours which are related to high scores in self-reported measures of impulsivity. One of which is compulsive buying (Lejoyeux *et al.*, 1997). This is the 'chronic and often repetitive behaviour of purchasing products as a primary response to experiencing negative event or feeling. This action is difficult to stop and can sometimes result in harmful consequences. These may be economical (such as becoming in debt or experiencing financial problems) but also psychologically and societally damaging' (O'Guinn & Faber, 1989). Pathological gambling is also associated with high impulsivity scores. The DSM-IV-TR (American Psychiatric Association Committee, 2000) and in the ICD- 10 (World Health Organisation International Classification of Disease, 2003) have classified problem gambling as an impulse control disorder. However, there is some confliction between researchers, although high levels of impulsivity have been reported in pathological gamblers, some research has found there is no difference versus controls and in some cases it has actually been reported that impulsivity is lower than in these individuals (Raylu & Oei, 2002; Lightsey & Hulseley, 2002; McDaniel & Zuckerman, 2003; Nower, Derevensky & Gupta, 2004).

Risky sexual practices have also been associated with high impulsivity levels (Williams *et al.*, 1992). Zuckerman & Kuhlman (2000) assessed risky sexual practice in

individuals using a four item scale: The first self-reported item identified how many different persons participants had ever had sexual contact with. The second was looking at sexual contact partner number within the last 12 months. The third looked at frequency of sexual contact in a typical week when they had a sexual partner. The last asked about birth control methods and also condom use. It was found that sexual risk-taking was related to high levels of impulsive sensation seeking. A quantitative meta-analysis of empirical research literature on normal personality and sexual risk taking reported that the number of partners, amount of unprotected sex, and high-risk sexual encounters (e.g., sex with a stranger) was significantly related to sensation seeking, impulsivity, and agreeableness on all the sexual risk-taking behaviours considered (Hoyle, Fejfar & Miller, 2000). Sensation seeking has also been attributed to sexual risk-taking among HIV positive persons (Wulfert *et al.*, 1999).

One of the most severe behaviours linked with impulsivity is suicide. Impulsiveness is considered to be one of the most frequently occurring risk factors associated with the engagement of maladaptive behaviours that involve serious self-injury (Anestis, Selby, & Joiner, 2007). Mann *et al.*, (1999) proposed the diathesis-stress model of suicidal behaviour. The vulnerability (diathesis) in this model are impulsive tendencies and increased instances of suicidal ideation. There are a number of studies which have found a connection between impulsive personality traits, ideation and in some cases action (Hull-Blanks, Kerr & Kurpius, 2004; Pfeffer, Jiang & Kakuma, 2000).

There are a number of mental disorders that have impulsivity as a core feature which confer risk. Pathological gamblers are more likely to attempt suicide. This has been attributed to high impulsiveness, suffering from the comorbid psychiatric condition as well as the social and financial disruptions caused by gambling. This combination of risk factors has been suggested to contribute to the potential for an individual to partake in suicidal behaviour (Kausch, 2003). A study compared individuals with Borderline Personality Disorder (BPD) to other diagnostic groups found those with BPD endorsed a variety of painful and provocative experiences more than controls. These endorsements mediates the interconnection between the diagnosis of BPD

and the likelihood of past suicide attempts (Teale, 2006). Impulsivity is also a characteristic of bipolar disorder. The history of severe suicidal behaviour in patients with bipolar was reported by Swann *et al.* (2005). This has been associated with abnormal levels of impulsivity and is manifested by the tendency to favour rapid, unplanned responses over those with adequate deliberation. Impulsive fluctuations seen in depressive disorders has been cited as being due to low 5HTT (Lindstrom *et al.*, 2004). Recently however there has been some research to suggest that although individuals that attempt suicide are more impulsive than controls, suicide itself is generally not done impulsively (Carey, 2008).

It is reported by the World Health Organization that aggressive acts and violence are one of the most prominent public health problems worldwide (Krug *et al.*, 2002). Aggression deeply impacts society which has a secondary impact on psychiatry. Barratt and Slaughter (1998) introduced a classification system for aggression consisting of three categories: premeditated, medically related, and impulsive. In relation to the impulsive aspects of aggression, Coccaro, (1998) went further by defining impulsive aggression itself as an aggressive behaviour which is conducted in a deliberate and non-premeditated fashion (see also Moeller *et al.*, 2001). Barratt *et al.* (1997) found that impulsive aggression was the result of certain neuropsychological and cognitive psychophysiological information processing patterns and that these measures were present in both samples of criminal and non-criminal individuals.

Further research investigated the relationship between impulsiveness and risk-taking aggressive behaviour in adolescents (high school and college students). The results demonstrate a significant link between high impulsiveness and the involvement of risk-taking behaviour compared to controls. This suggests that adolescents that show increases in impulsivity are at a greater risk of self-harm and injury to others. Results were so conclusive individuals that were found to be in the high impulsive group could be targeted by an intensive education intervention. This would develop coping strategies to help manage the individual's inability for delayed gratification and general lack of impulse control in an attempt to reduce levels of

aggression and other maladaptive behaviours (Stanford *et al.*, 1996). These findings were supported by another adolescent based sample study which reported that high thrill-seeking behaviour and low self-control caused greater levels of delinquency. Interpersonal delinquency is highly related to aggression. This was found to be influenced by low levels of self-control in participants (Pfefferbaum & Wood, 1994).

There have also been connections made to impulsivity and risky road behaviour. Scoring highly in self-report measures of impulsivity has been strongly correlated to engaging in drink and dangerous driving. These behaviours include not using a seatbelt and in a more general sense a greater lack of care in children when it comes to road safety (Pfefferbaum & Wood, 1994; Stanford *et al.*, 1996; Eensoo *et al.*, 2007). The risky road behaviour seen in children also extended to adults in high sensation seeking groups, e.g. an increase in pedestrian crossing when on a red light (Rosenbloom, 2006) behaviours which have the potential to put the individual and other road users at risk of injury (Vermeiren *et al.*, 2003). In summary it is clear that impulsivity is the cause of, and significant contributor to many public health problems and psychiatric disorders with far-reaching personal, social and economic consequences for the individual and society. This is compounded by the significant disagreement among researchers and clinicians regarding the correct definition of impulsivity and how it should be measured and thus there is a need for considerable further research in this field (International Society for Research on Impulsivity 2015).

Impulsivity has been broken down in the state-trait anger theory (Spielberger, Krasner & Solomon, 1988) into two sub-constructs, state and trait impulsivity. State impulsivity is in reference to a subject's short-term transitory state at any given time, which can be affected by or change the response to an event. Trait impulsivity is a more enduring personality characteristic. Whereas someone state can change readily a trait remains stable determining behavioural outcomes across a range of situations longer term (Deffenbacher *et al.*, 1996). Swann *et al.*, (2009) proposed a division of impulsivity in understanding antisocial personality disorder similar to that of state and trait using the Barratt Impulsiveness Scale¹¹ (Patton, Stanford & Barratt, 1995) measuring the trait impulsivity of a group of antisocial personality disorder subjects. The findings highlighted a dissociation between state and trait impulsivity.

Christodoulou *et al.* (2006) gained similar results when studying people with bipolar disorder. The relationship between trait impulsivity (measured using BIS-11) and state impulsivity by response disinhibition (Hayling sentence completion task) appeared to be orthogonal. These studies would indicate that there important distinctions between long (trait) and short (state) term impulsivity.

2.6 General theories of impulsivity

Ego (cognitive) depletion and self-control.

Self-control has been described as a fundamental ability and a defining feature of the human animal. It allows us to sustain a mental capacity to override or alter our own behaviours thoughts and emotions (Inzlicht & Schmeichel, 2012). Although this area has been studied for some time (see Mischel & Gilligan, 1964 for an early example) it was only in the early 2000s that a greater interest was shown by the research community. A key experiment by Roy Baumeister and his colleagues was one of first to demonstrate how ego depletion has an effect on a variety of contexts and situations (Baumeister *et al.*, 1998). It was found that participants who resisted eating chocolates were then subsequently less capable of completing a puzzle task. This led to the creation of The Resource Model of Self-control. The ego (or cognitive) depletion theory of impulsivity refers to self-control as 'the capacity for altering one's own responses, especially to bring them into line with standards such as ideals, values, morals, and social expectations, and to support the pursuit of long-term goals' (Baumeister *et al.*, 2007). The model deemed self-control as an inner capacity which has a reliance on a limited internal resource store. Baumeister metaphorically relates the concept of self-control as a muscle. A muscle that requires energy to function which can be both strengthened and weakened. Using this 'muscle' (self-control) will cause it to weaken (ego depletion) causing reduced efficiency in future tasks. A variety of experiments support this muscle analogy of self-control and ego

depletion (Baumeister & Heatherton, 1996; Baumeister, Heatherton & Tice, 1994; Baumeister & Tierney, 2011; Muraven & Baumeister, 2000).

The main evidence for this theory is found through experiments utilizing the dual-task paradigm (Fisk, Derrick & Schneider, 1986). This neuropsychological technique requires the participant to perform two tasks simultaneously. The level of performance in the dual task is then compared to the single-task. When performance on one of or both tasks is reduced while they are conducted simultaneously compared to individually it can be inferred that the two tasks interfere with each other. If this is the case than the assumption can be made that each task must compete for the information processing resources needed to complete it. Therefore human processing resources must be limited but shareable (Kahneman, 1973; Navon & Gopher, 1979) with the ability to be subdivided into several classes (Wickens, 1991). Several studies have demonstrated this (see table 3).

Table 3: Dual-task examples

| Study | Ego depleting task | Result |
|----------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------|
| Stucke & Baumeister (2006) | Resisting tempting foods. | Increased denigration of an insulter's competence. |
| DeWall <i>et al.</i> (2007) | Ignoring salient visual stimuli. | Increase in aversive noise blasts directed toward an insulter. |
| Denson <i>et al.</i> (2011); Finkel <i>et al.</i> (2009) | Acts of self-control. | Loss of self-regulation of aggressive impulses. |
| Vohs <i>et al.</i> (2008) | Decisions between consumer products. | A reduction in tolerance in a pain test. |
| Hagger <i>et al.</i> (2010). | Meta-analysis containing studies which involved a series of choices. | Decrease in self-control task performance |

There have been a number of studies that present a physical explanation for this metaphoric cognitive resource. Bloodstream glucose levels is the most notable example (Gailliot *et al.*, 2007) exerting high levels of self-control has been found to

significantly reduce blood glucose. This reduction could be seen as 'ego depletion' therefore an increased intake of glucose may counter this ego depleting effect (Masicampo & Baumeister, 2008). Research by Denson *et al.*, (2010) found that consuming glucose improves levels of self-control and eliminated the ego depletion effect. Similar results were found when participants gurgled a sugary drink (Molden *et al.*, 2012) This proposition has however been challenged by a number of studies (Beedie & Lane, 2012; Kurzban, 2010; Molden *et al.*, 2012).

Other factors reduce the ego depletion effect including; motivational incentives (Muraven and Slessareva, 2003), positive mood (Tice., 2007) and an individual's belief in the amount of willpower available to them (Job, Dweck, and Walton, 2010). If this is the case than it questions the concepts proposed by the resource model. The physical drainable resource which causes the ego depletion effect can be restored through subjective perceptions and self-affirmation. This results in the maintenance of self-control without the need for glucose (Clarkson *et al.*, 2010; Schmeichel and Vohs, 2009).

Automatic vs. controlled processes/cognitive control

Dual Process Theories of automatic vs. controlled cognitive processing proposes that mental operations are done in one of two ways, being either automated or controlled. Generally speaking, processes that are automatic require previous experience or informal heuristics of a response and do not use higher levels of cognition (Amsel *et al.*, 2009). Alternatively controlled decisions are predominantly conscious and effortful processes when an individual decides between a number of alternative outcomes deliberating the decision (Smith & DeCoster, 2000).

The first notion of this theory was from the cognitive-experiential self theory within contemporary psychology which differentiated between two different ways of information processing: analytical-rational and intuitive-experiential (Epstein, 1994, 1996). This area of research has gathered momentum over the last two decades with several variations of this model being proposed; Metcalfe and Mischel's (1999) "hot"

vs “cool” system and the reflexive-impulsive model (Strack and Deutsch, 2004; Hofmann, Friese & Strack, 2009) with many others showing interest in this area (e.g., Chaiken & Trope, 1999; Barrett, Tugade & Engle, 2004).

The automatic process has been attributed to being an evolutionarily old neurobiological system which; is highly reactive to emotions, uses previous associative responses and is impulse based. It has also been termed a reflexive system (Strack & Deutsch, 2004). There are some main criteria of behaviours made through this system (Gawronski & Creighton 2013). The cost of the decision is of a very low cognitive load, the decisions themselves can seldom be stopped, the act is often unintentionally and done on a subconscious level.

The system which is evolutionarily more recent involves a great level of planning and is often referred to as the reflective or deliberative system. This system was later to develop compared to the automatic system (Galvan *et al.*, 2006; Steinberg, 2007). This Controlled process has features that are antagonistic to the reflexive counterpart (Gawronski & Creighton, 2013). Decisions are conscious with cognitive resources being required to make the action. The individual also has control whether or not to complete the behaviour.

Previously these systems were seen as completely separate operations; however, recently they seem to work on more of a continuum with most impulsive behaviours having both a controlled and automatic aspect (Gawronski & Creighton, 2013). Each uses a different facet of available information (Rudman, Phelan & Heppen, 2007). There is a growing amount of evidence that these two systems may adapt in different ways through experience. This differential learning creates a parallel of competing paths to the final action, a process which needs repeated mediation (Daw, Niv & Dayan, 2005). There are a number of factors which determine which of these systems will be responsible for the behavioural outcome. Within cognitive psychology there have been several studies which evaluated the variables which affect intuitive vs. reflective thinking. The deliberative (or reflective pathway) has been found to be dominant when an individual has pre-acquired knowledge or expertise in the given situation (Evans, 2003). This pathway has also been found to be favoured after; receiving a degree of training (Nisbett *et al.*, 1983), having a good general level of

intelligence (e.g. Barbey & Sloman, 2007) and critical thinking ability (West, Toplak & Stanovich, 2008). However, there are a number of factors (both external and dispositional) which cause declines in the use of the deliberative system these include sleep deprivation, high cognitive load and excessive alcohol consumption. With internal dispositional variables such as working memory capacity, low conscientiousness and self-control (Carver, Johnson & Joormann, 2013). The continued reliance on the reflexive response pathway underlies some psychopathologies including impulsive violence, high sensation seeking behaviour as well as high emotion reactivity, externalizing problems and substance abuse (Carver & Miller, 2006 Cyders *et al.*, 2009; Whiteside & Lynam, 2003).

Inter-temporal choice

During the span of an individual's life there are many inter-temporal choices that have to be made. People find themselves deliberating between the benefits and potential costs of the actions they take which may differ significantly on the time in which they are made. Making the correct 'advantageous' choices is important for survival, adaptation and success of an individual. These choices may consist of choosing to quit smoking to reduce the risk of future disease or carrying on to help relieve the more immediate stressors in life. The importance of these decisions and the impact of incorrect decision has led to the rapid development of the field neuroeconomics (Glimcher & Rustichini, 2004). Maladaptive neuroeconomic processing has associations of being a core deficit in a number of neuropsychiatric conditions, these include: depression, ADHD, addiction and pathologies relating to abnormal levels of impulsivity (Platt & Huettel, 2008). Impulsivity is expressed as an inconsistency in intertemporal choice, with a greater amount of delay discounting. Given two similar rewards, humans show a preference for a smaller but immediate reward that arrives sooner than a larger but delayed one. The value of the later reward is 'discounted' by a factor that increases with the length of the delay (Camerer, 2005). Generally people tend to be more patient in regards to the distant future but have higher levels of impulsivity in the near future. Poor self-control and

high delay discounting has also been linked to reduced cognitive ability, memory and intelligence (Shamosh and Gray , 2008; Shamosh *et al.*, 2008).

The discounted utility model (Samuelson, 1937) provides an economically viable framework for intertemporal choice theory. The driving factor to make a choice (discount rate) decreases by a fixed percentage for each time unit that a reward is delayed (Frederick *et al.*, 2002) this relationship is represented by an exponential discounting curve (see figure 21 below). However this means that the model proposes that a temporal delay leads to the same proportional degree of discounting occurring regardless of when it transpires (Loewenstein *et al.*, 2008). Although consistent with economics; this model struggles to explain the behaviour of people who tend to choose to discount future rewards at a greater rate when the delay occurs sooner in time. This has led behavioural economic and some neuropsychopharmacological studies to theorise of a new 'hyperbolic discount model' (Glimcher, Kable & Louie, 2007). The rate at which people discount future rewards is reduced as the delay increases. The most common examples are based on monetary rewards. If someone was given the option to receive £70 today or £100 tomorrow the vast majority would choose to wait an additional day for the extra £30. Interestingly if the delay is then extended to 3 months people would be less likely to wait for the additional money. This effect only occurs within a certain time period once the threshold is crossed the 'devaluation effect' is diminished, so if the options would be to wait a year for £70 or 18 months for £100 people would tend to choose the higher monetary amount.

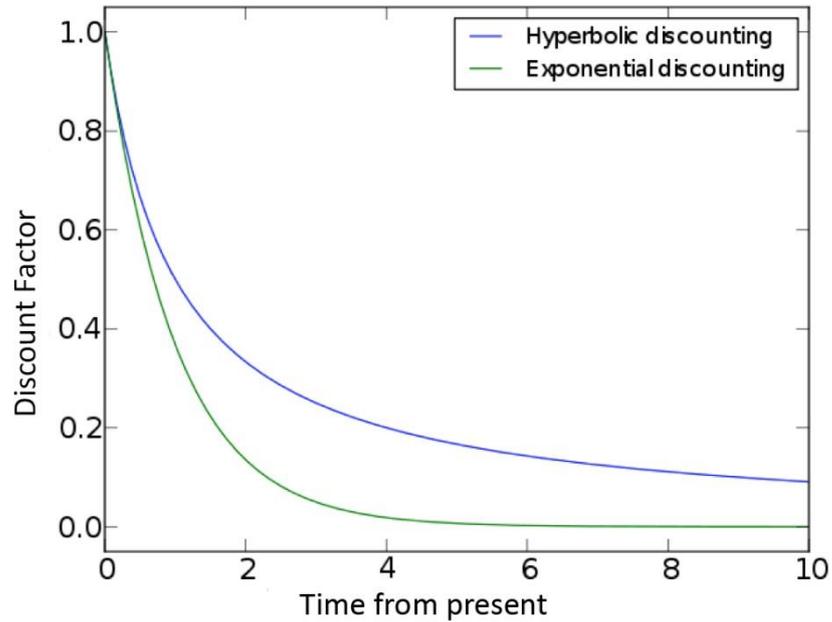


Figure 21: Discount model curves.

Inhibitory control

Inhibitory control refers to an individual's ability to override a natural, habitual, or dominant behavioural response with a different but goal-oriented action (Ilieva, Hook & Farah, 2015). The process of adapting a pre-existing learned response is a key facet of cognitive control (Guiney & Machado, 2013).

Impairment of this mechanism has been related to both addiction and ADHD (Ilieva, Hook & Farah, 2015). This theory defines impulsivity as an executive function deficit manifested in the inability to inhibit a behavioural response. The more impulsive you are the harder it is to inhibit an action (Logan *et al.*, 1997). This is reinforced by correlations observed between inhibitory control and standard self-report measures of impulsivity (Enticott, Ogloff & Bradshaw, 2006). There are several constructs that make up inhibitory control each of which has been related to a type of psychopathology (Nigg, 2000). Nigg (2000) developed a taxonomy including these various forms of inhibitory control, this includes the following:

- Interference control, to subdue a stimulus that interferes with the completion of a primary task (distractor suppression).

- Cognitive inhibition, to suppress irrelevant thoughts which may have a negative effect on attentional resources and working memory.
- Behavioural inhibition, to suppress a pre-potent response resulting in the correct behavioural outcome.
- Oculomotor inhibition, a reduced ability to stop reflexive saccades. This would usually occur when a stimuli of high attentional value enters the visual field which is irrelevant to the task.

Motivational inhibition:

- In response to punishment, how actions are influenced by potential punishment, In the case of impulsive actions a reduction in thought of the outcomes of a risky behaviour are observed.
- In response to novelty, the impact a new stimulus has on an individual, which can either trigger a fear or curiosity response.

Automatic inhibition of attention:

- Recently inspected stimuli, suppressing attentional and oculomotor saccades of recent stimuli which have lost attentional importance.
- Neglected stimuli, suppression of information in locations that are not presently being attended to.

2.7 Impulsivity, mood and personality

Personality is defined by the American Psychology Association (VandenBos, 2007) as “individual differences in characteristic patterns of thinking, feeling and behaving”. An individual’s personality is made up of a number of personality traits. This concept is referred to as trait theory (or dispositional theory) in psychology. Traits are habitual patterns of behaviour, emotion and thought. Although traits have large variations between people they remain relatively stable over time (Mischel, Shoda &

Smith, 2004). However more recent research shows that personality traits may be malleable by environmental influences (Briley & Tucker-Drob, 2014; Jeronimus *et al.*, 2014). Traits are in contrast to states which are more transitory dispositions. Traits are seen as dimensions such as extraversion vs introversion, with each person falling within a spectrum of how regularly or intensely they experience them (Eysenck, 1991; Costa & McCrae, 1992).

Mood, Emotion and Affect

Historically the terminology of mood, affect and emotion have been used interchangeably (Batson, Shaw & Oleson, 1992). However more recent research has suggested that there are lines of demarcation between them (Alpert & Rosen, 1990; Batson *et al.*, 1992; Beedie, Terry, & Lane, 2005; Russell, 2003; Russell & Feldman Barrett, 1999). An amalgamation of views amongst authors has allowed for more robust classification of these terms.

Moods are emphasized to be diffuse and global states of mind. Commonly low in intensity but lasting for extended periods of time (hours or even days). Frijda (2009, p.258) defines mood as "the appropriate designation for affective states that are about nothing specific or about everything-about the world in general". An additional defining feature is that mood shows little response synchronization. This is to say that mood is temporally remote from its causation (Morris, 1992). Consequently, the cause of a mood may not be easy to identify by the individual experiencing it. Although recognised as being internal and personally subjective, mood state can often be recognised externally by others by posture and behaviour (Schinnerer, 2007). Long term disturbances in mood present themselves as psychopathologies such as clinical depression and bipolar disorder.

There is a long history within psychology in the endeavour to define the term 'emotion' (Widen & Russell, 2010). Historically emotions have been seen as multi-component behavioural patterns (Newman, Perkins & Wheeler, 1930) as well as

‘perceptual’ and ‘cognitive’ processes. (Spencer, 1855). These claims are echoed in more recent definitions, emotion is seen as both a positive and negative driving force in the motivation of behaviour (Gaulin & McBurney, 2003). The positive or negative nature of the experience determines the pattern of physiological activity associated with that emotion (Schacter, 2011). Some theories infer that emotion is a simple syndrome of components made up of motivation, feeling, behaviour, and physiological changes. With emotion presenting itself as ‘not a single one nor the sole entity that causes these components’ (Barrett & Russell, 2015). Some theorists describe emotions as discrete and consistent responses to internal or external stimuli that have a particular significance to an organism’s experience. These responses are often brief and result in a coordinated set of responses; verbal, physiological, behavioural, and neuromechanical (Fox, 2008).

Researchers have attempted to demystify the layman concepts described as emotion (Averill, 1980; Frijda *et al.*, 1995). The number of proposed emotions is also debated. One of the most influential thinkers in the field Ekman (1992) suggests six primary emotions: anger, disgust, fear, happiness, sadness, and surprise. Whereas categorization that includes the more complex emotional constructs such as the emotion annotation and representation language (EARL) proposed by the Human-Machine Interaction Network on Emotion (HUMAINE) classifies 48 facets (Emotion-research.net. 2016). Although brief these conscious experiences of intense mental activity are highly ambiguous, an issue that has continuously arisen in the history of emotion research (Cabanac, 2002; Schacter, 2012). This problem has been reported as early as the 1930s with Duffy (1931) questioning the validity of emotion as a workable scientific term “we should study these phenomena in their own right, and under precise labels that do not mean different things on different occasions and to different writers” (p. 103; see also Dunlap, Meyer & Hunt as discussed in Gendron & Barrett, 2009). There have also been interdisciplinary disagreements of how to use emotion terms and classifications. These are primarily between the humanities and the social / behavioural sciences, which rarely agree on how to use them (Scherer, 2004a; Scherer, 2004b; Scherer, 2004c). It has been proposed that even the term “emotion” itself may be a western conceptualisation that can only be used within

the paradigm of western thinking and psychology (Danzinger, 1997; Gendron & Barrett, 2009).

Affect is the personal experience of emotion, it is a key step in an organism's interaction with a stimuli (Hogg, Abrams & Martin, 2010). It can also refer to the external 'displays' an organism presents when experiencing an affect be that its facial, vocal, or gestural behaviour (VandenBos, 2007). Russell & Feldman Barrett (2009, p. 104) define affect as a "neurophysiological state consciously accessible as a simple primitive non-reflective feeling most evident in mood and emotion but always available to consciousness" . Affective states are psycho-physiological in nature made up of three principal dimensions: valence, motivational intensity and arousal (Harmon-Jones, Gable & Price, 2013): Valence equates to the extent a state is perceived to be either positive or negative. More specifically emotional valence is the consequences of experience a said emotion, emotion-eliciting circumstances, or subjective feelings or attitudes regarding an emotion (Harmon-Jones, Harmon-Jones, Amodio & Gable, 2011). Motivational intensity refers to an impulsion to act. It is measured by the strength of a motivational urge to either move towards or away from a stimulus (Harmon-Jones, Harmon-Jones & Price, n.d.). Arousal is observed in two ways objectively by the level of activation seen in the sympathetic nervous system and subjectively via self-report measures. Arousal is closely related to motivational intensity however arousal requires no measurable action (Gable & Harmon-Jones, 2013). Some examples of affect include: tension and relaxation, pleasure and displeasure, energy and tiredness Russell (2003).

Impulsivity

It is generally acknowledged that impulsivity consists of many facets (Gerbing, Ahadi & Patton, 1987; Malle & Neubauer, 1991; Parker, Bagby & Webster, 1993). There is, however, limited research to suggest which aspects of impulsivity should be recognised as mood, emotion or core affect. In terms of a broad definition, "impulsivity encompasses actions that appear poorly conceived, prematurely

expressed, unduly risky, or inappropriate to the situation and that often result in undesirable consequences” (Daruna & Barnes, 1993, p. 23). The diversity of impulsivity and its manifestation as both a behavioural and cognitive phenomenon means there are an array of models which have been developed to outline its different components (Barratt, 1965; Strakowski *et al.*, 2009; Swann, 2009; Whiteside & Lynam, 2001). It is important to understand these different dimensions as impulsivity is related to a number of psychopathologies: gambling addiction, alcohol abuse, depression, antisocial personality disorder, suicidal ideation, Bi-Polar disorder and impulse buying (Maccallum *et al.*, 2007; Swann *et al.*, 2002; Zuckerman & Kuhlman, 2000; Zouk *et al.*, 2006; Swann *et al.*, 2009; Swann *et al.*, 2003; Billieux *et al.*, 2008).

A distinction (as seen in the state-trait anger theory Spielberger, Krasner & Solomon, 1988) which helps with categorisation of this term is made by splitting impulsivity into two sub-constructs: state and trait. State refers to a transitory state which relates to a particular time in response to a specific event, e.g. fluctuations in impulsivity dependant on menstrual cycle stage (Howard, Mason & Taghavi, 1994). Whereas a trait refers to an enduring personality characteristic which determines an individual’s behavioural responses across a wide range of situations, e.g impulsivity is elevated in people with manic personality traits (Deffenbacher *et al.*, 1996; Najt *et al.*, 2007; Strakowski *et al.*, 2010; Swann, 2009; Swann *et al.*, 2001). In short, trait impulsivity is a long-term mood, while state impulsivity is a short-term affective state. Evidence for this separation within the impulsivity concept has been demonstrated by a number of researchers: Swann *et al.* (2009) suggested this dissociation. The Barratt Impulsiveness Scale Version 11 (BIS-11; Patton & Stanford, 1995) was used to measure trait impulsivity in a number of patients suffering from antisocial personality disorder, a dissociation between state and trait impulsivity was found in questionnaire results. Christodoulou *et al.* (2006) also used the BIS-11 (measuring trait) in addition to a response disinhibition task (measuring state) with a bipolar cohort. No significant relationships were found between tests. This suggests that trait and state impulsivity are orthogonal. Finally State impulsivity presents itself differently from trait impulsivity by attentional biases in participants. This is seen by

a greater attention towards affectively neutral (cognitive domain) or affective events (affective domain) (Chan, Raine & Lee, 2010). Although this evidence would suggest these sub-concepts do exist they may still occur in unison. High levels of impulsivity occur in the manic phase of bipolar disorder (state impulsivity) in both euthymic and manic individuals in addition to a higher level of trait impulsiveness seen in healthy individuals (Swann *et al.*, 2001; Swann *et al.*, 2001). Collectively the research mentioned previously highlights the importance of differentiating between trait and state impulsivity, be it in the method of measurement of impulsivity or the potential effect it may have on the behavioural responses of participants in research.

2.8 Theories of Mood, affect and emotion.

General Emotion Theory: Evolutionary

In evolutionary theory (Darwin, 1872) emotions have been seen to be used in aiding survival. Darwin believed that emotions evolved through natural selection. As evolutionary theory began to develop it was believed that basic emotions and social emotions evolved to motivate/modulate (social) behaviours that were positively adaptive in the ancestral environment (Gaulin & McBurney, 2003). Facial expressions (Ekman, 1971) became of increasing significance in the study of emotion. Foundation research involve individuals being asked to identify photographs of facial expressions. It was found that expressions are universally associated with particular emotions, these were found across cultures and even in preliterate individuals. The only emotions that preliterate participants sometimes struggle to identify between are fear and surprise (Ekman, 1971). Although this research does provide strong evidence Ekman showed caution that this does not necessarily prove Darwin's theory (Ekman, 1993). This study was also extended to identify the similarities between human expressions and primates, the most universally recognised are: anger, fear, disgust, sadness, and enjoyment (Ekman, 1993). They primarily served as non-communicative adaptive behaviours; when experience fear widened and increase

eye movement increase ones visual field allowing for better threat detection and response. These reactions later repeated observation to member of the social group became more exaggerated in order to then fulfil a more socially communicative function (see Table 4 for full list of emotions). Facial expressions of pride lead to an automatic higher social status than to those expressing other emotions (Shariff & Tracy, 2011)

Table 4: Expressed emotions and adaptive functions (from Shariff & Tracey, 2011).

| Expressed emotion | Initial physiological function | Evolved communicative function |
|---------------------|---------------------------------------------------------------------|-----------------------------------------------------------------|
| Fear | Increased visual field and speed of eye movement from widened eyes. | Warning of potential threats. Appeasement to aggressor. |
| Surprise | Increased visual field from widened eyes. | N/A |
| Disgust | Constriction of face openings reduce dangerous inhalations. | Warning of dangerous foods, behaviours, and ideas. |
| Happiness | N/A | Absence of threat. |
| Sadness | N/A | Vision handicapped by tears to show appeasement. Gain sympathy. |
| Anger | N/A | Warning of impending threats. Signals dominance. |
| Pride | Increased lung volume in preparation for encountering challengers | Increased social status. |
| Shame/Embarrassment | Reduces and hides vulnerable body areas from potential attacks. | Decreased social status. Wish for appeasement. |

Cognitive-mediational theory

A group of theories argue the importance of cognitive processes (judgments, evaluations, or thoughts) in emotion formation. Richard Lazarus (1991) believed emotions must have cognitive intentionality. This is conscious or unconscious cognitive activity to help interpret an emotion through context. This was thought to be achieved through conceptual processing. Emotion is seen as a disturbance within a chain of events: The individual cognitively evaluates the stimuli resulting in an emotion response (cognitive appraisal). This cognitive change starts a physiological reaction (heart rate/adrenal secretion). Which then results in the individual to act on the feeling of the emotion in a certain way. The clarity and intensity of emotions are controlled through cognitive processes, which can be altered by relationships between the person and the environment.

Somatic theories

Somatic theories challenge cognitive theories by claiming that biological responses, not cognitive interpretations are fundamental to emotion. The most influential theorists in this field are James–Lange & Cannon-Bard.

James–Lange theory (1922) suggests that perceiving an external stimulus leads to a physiological reaction (through the vasomotor centre). The emotional reaction is then governed by how the physical reactions are interpreted. Cannon–Bard theory (Cannon, 1927) challenges James–Lange proposing that people can experience psychological changes associated with emotion without feeling the emotion itself. Thalamus activation triggers a neural response resulting in physiological reaction concurrently with neural activity triggering an emotional experience. This explains why emotional responses occur too rapidly to be a reaction to physical state meaning that the physical and psychological experiences happen simultaneously but are not caused one on another.

Hybrid theories

The two-factor (Schachter–Singer) theory of emotion (Schachter, 1962) proposes that emotion is the results of two factors: physiological arousal and cognitive label. When emotion is experienced so is physiological arousal. The individual then analysis the immediate environment for emotional cues to aid in labelling in this heightened state. Occasionally this can cause misattribution of emotion when the external labels are unclear (Pruett , 2011).

Perceptual theory

This neo-Jamesian approach argues that bodily responses are vital to emotions but emphasize the importance of internal perceptions of the emotion. Bodily changes triggered by certain situations are perceive as the meaningful content of the emotion. However, mental cognition is not needed. It is the perception of bodily changes that brings meaning to the emotion. Similar to other senses like vision or touch which inform the individual about their environment interaction (Prinz, 2004; Laird, 2006). Thus emotions can be seen as a subjective concept only reflecting the exclusive mind of the subject experience them. Theories based on perception group multiples instances of perceptions together to form the concept of an emotion (Goldie, 2007).

Situated perspective on emotion

Situated perspective draws attention to the external factors in the development and communication of emotion within the situationism paradigm of psychology (Griffiths & Scarantino, 2005). This theory is designed to function within a social context. Emotion is seen as a relationship reconfiguration manifested through delivering social signals. This engagement is not mediated by conceptual thought but rather is constructed through interactions with the environment “both synchronically in the

unfolding of a particular emotional performance and diachronically, in the acquisition of an emotional repertoire” (Griffiths & Scarantino, 2005 p.2). Emotion stimulates the development of social relationships, a mediator of behaviours expressed by other organisms. In some cases this manipulation can be seen as a strategic move to alter the transactions between organisms.

2.9 Impulsivity within personality, mood and behaviour.

The relationship between impulsivity, personality and emotional state has been well documented particular in the case of addictive behaviours. This interconnection is usually confounded with other substances and situational factors. Alcohol, and narcotics are used as negative mood regulators to desensitize anxiety and discomfort. (Cooper *et al.*, 1995; Howell *et al.*, 2011; Galen *et al.*, 2001; Stewart *et al.*, 2001; Cheethman *et al.*, 2010; Dorard *et al.*, 2008; Quirk, 2001; Wu *et al.*, 2011). Increases in smoking and binge eating has been observed during stressful times; displaying a shift towards instant gratification away from longer term healthier behaviours (Abrantes *et al.*, 2008; Shi *et al.*, 2011; Greeno & Wing, 1994; Magid *et al.*, 2009). Other research has found that students who identified gambling as a method of relief or reward were more financially unstable, showing significantly higher impulsivity scores than those who did not have these expectations (Shead & Hodgins, 2009). The impulsive decision making associated with gambling is an attempt to alleviate negative emotional state (Tice *et al.*, 2001).

Emotional dysregulation

Emotion regulation is a mechanism that allows an individual to manipulate their emotions (this can be both intentionally or unintentionally). This grants a greater amount of control of one’s emotional state (Aldao *et al.*, 2010). Previously research shows that failures in this mechanism cause maladaptive emotion regulation. A

precursor for the development and maintenance of psychopathologies (Gross & Muñoz, 1995; Moore *et al.*, 2008). This occurs through conflicting self-regulation goals when under emotional stress. Attention is shifted from longer term goals centred on self-regulation and maintenance to more immediate endeavours to diminish the experience of emotional distress; even if in the long term it is to the individual's detriment (Tice *et al.*, 2001).

Leading theories on the aetiology of Bipolar Disorder (BPD)(Crowell *et al.*, 2009, Koenigsberg *et al.*, 2009; Linehan, 1993) propose that it is best understood as an emotion dysregulation disorder. Heightened emotional sensitivity and an ineptitude to regulate emotional responses result in marked impulsive behaviour, during the manic episodes characterised in BPD patients.

Reinforcement Sensitivity Theory (RST)

RST is based on three brain-behavioral systems relating to the individual differences seen in sensitivity to reward, punishment, and motivation. RST is used to study and predict anxiety, impulsivity, and extraversion (Corr, 2008), both in and outside of clinical settings (Clark, Matthew & Loxton, 2012). The theory was developed from Gray's biopsychological theory of personality (Gray & McNaughton, 2003) however it now proposes functional subsystems while distinguishing between fear and anxiety. This theory was informed by studies on reward, punishment, and motivation and the biology behind personality traits (Gray & McNaughton, 1982). Eysenck's Extraversion-Arousal Hypothesis states that 'under low stimulation conditions, introverts (low scoring individuals on the extravert scale) will be more highly aroused than extraverts'. This increased stimulation happens to a point but when stimulation becomes too high introverts become over-aroused which results in decreases in arousal due to feedback within the ARAS. Extraverts show greater increases in arousal under high stimulation (Corr, 2004). Impulsive reactivity theory argues that over-reactivity to emotions is caused by this dominance in the reflexive system. This

can also occur in both reactive violence and high sensation seeking (Carver, Johnson & Joormann, 2013).

Mania

One of the most notable personality traits associated with impulsivity is mania. The criteria used for diagnosing mania are based on the number of behaviours an individual exhibits with no regard for future consequences. These may be of a financial, health or other indiscretion nature. Manic patients often fear a loss of control; an integral part of impulsivity (Janowsky, Leff and Epstein, 1970). Mania is a defining dimension of bipolar disorder, a behavioural extreme of impulsivity (Strakowski *et al.*, 2009). It is still unknown if impulsive behaviours associated with mania span all aspects of impulsivity, it may be that they are just attentional deficits or extension of moods (Bearden, Hoffman & Cannon, 2001). Bipolar patients with mania display abnormalities in impulsivity screenings in comparison to healthy subjects. This difference may be due to medication however this was not considered the case in the most pronounced difference, delay gratification (measured by a delayed reward task). This extends from simple inattention or speed of decision to the evaluation of reward relative to delay (Strakowski *et al.*, 2009). Predictably this difference in impulsivity is higher in manic than in euthymic bipolar sufferers (Swann *et al.*, 2001; Swann *et al.*, 2003). Research investigating this link further introduces a comparison to measures of depression. Impulsivity(measure by the BIS) was found to relate differentially between depression and mania. 'General and attentional impulsivity correlated independently with depression and mania scores. Motor impulsivity correlated with mania scores, while non-planning impulsivity correlated with depression scores' (Swann *et al.*, 2008). Depressive symptoms consisted of anhedonia, hopelessness and suicidality which correlated most strongly with BIS scores. It is therefore hypothesised that a combination of both depression and mania manifests itself into the most dangerous of impulse behaviours (Corruble , Damy & Guelfi, 1991; Simon *et al.*, 2001; Pezawas, Stamenkovic & Jagsch, 2002). A summary

of the demographic, clinical variable, medication, and behavioural relationships is reported in figure 22 below.

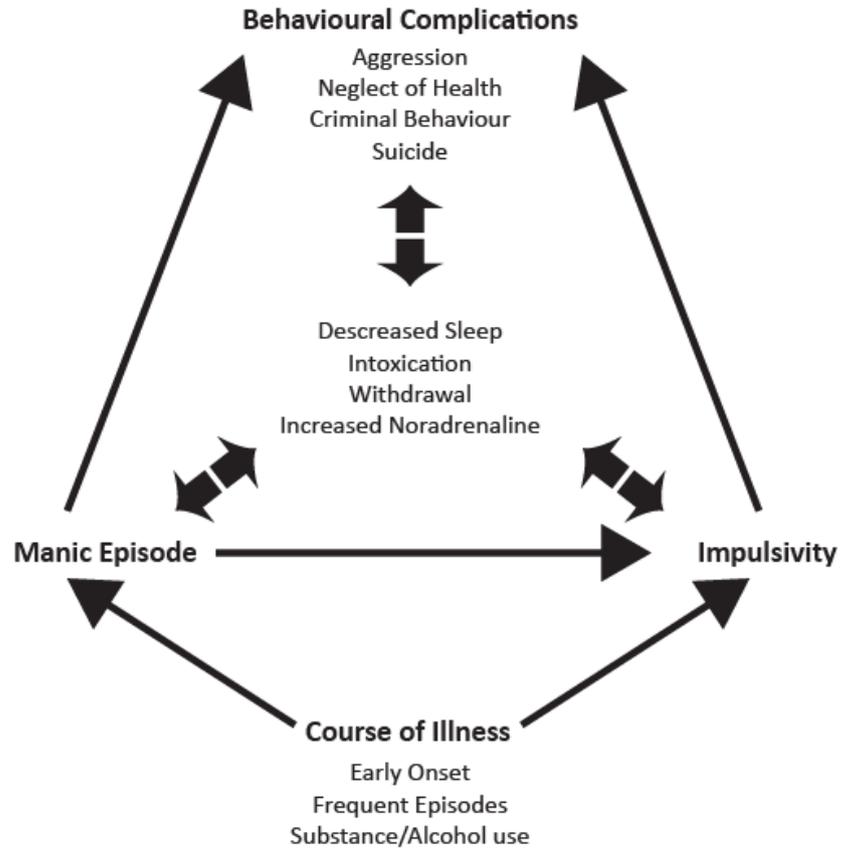


Figure 22: Summary of interactions between mania and impulsivity (Swann, et al, 2009).

2.11 Measuring Impulsivity

Previous research has traditionally used one methodological framework when investigating impulsivity. This focused approach hinders comparisons between impulsivity tasks, personality/mood traits and neurological changes. Thus it only provides an undifferentiated view of impulsive characteristics (Carrillo de la Peña & Barratt, 1993). As impulsivity is usually referred to as a multifaceted concept (Barratt & Slaughter, 1998; Nigg, 2000), it would make more sense to test it in a way which could cover more of its sub-constructs. This would ultimately provide a more accurate characterization of impulsivity within a sample. Self-report and laboratory behavioural measures remain the two most commonly used methodologies for testing impulsivity. The self-report questionnaires tend to correlate with each other however have generally shown poor continuity with laboratory behavioural measures (Barratt & Patton, 1983). This may suggest that behavioural measures are identifying unique phenomena. Laboratory and neurological measures also offer objective performance-based forms of assessment that are sensitive to temporary (state) variations. Although better at evaluating longer term (trait) characteristics self-report measures rely on accurate recall and honest responding. The main impulsivity measures from these three theoretical perspectives can be seen in table 5:

Table 5 : Overview of Impulsivity measurement methods.

| Measure | Type of Measure | Theoretical perspective | Test Dimensions |
|------------------------------------------------------------------------------|--------------------------------|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Barratt Impulsiveness Scale 11 (Patton, Stanford, Matthew & Barratt, 1995) | Self-Report personality scale | Personality/Mood | <ul style="list-style-type: none"> • Attention • Cognitive Instability • Motor • Perseverance • Self-Control • Cognitive Complexity |
| The Eysenck Impulsiveness Scale (Eysenck, Pearson, Easting & Allsopp, 1985). | Self-Report personality scale. | Personality/Mood | <ul style="list-style-type: none"> • Impulsiveness • Venturesomeness • Empathy |
| The UPPS Impulsive Behavior Scale (Whiteside & Lynam, 2001) | Self-Report personality scale | Personality/Mood | <ul style="list-style-type: none"> • Urgency • Lack of premeditation • Lack of perseverance • Sensation seeking |
| Lifetime History of Impulsive Behaviors (Schmidt, 2000) | Self-Report personality scale | Personality/Mood Lifetime history | <ul style="list-style-type: none"> • Impulsivity • Sensation seeking • Trait anxiety • State depression • Empathy • Social desirability |
| Dickman Impulsivity Inventory (Dickman, 1990) | Self-Report personality scale | Personality/Mood | <ul style="list-style-type: none"> • Dysfunctional Impulsivity • Functional Impulsivity |
| Behavioral Inhibition System/Behavioural Activation System (Carver, 1994) | Self-Report personality scale | Personality/Mood | <ul style="list-style-type: none"> • Behavioral Inhibition System • Behavioural Activation |

| Measure | Type of Measure | Theoretical perspective | Test Dimensions |
|-------------------------------------------------------------------|-------------------------------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sensation Seeking Scale (Zuckerman, Kolin, Price & Zoob, 1964) | Self-Report personality scale | Personality/Mood | <ul style="list-style-type: none"> • Thrill and Adventure Seeking. • Disinhibition • Experience Seeking • Boredom Susceptibility |
| Impulsive/Pre meditated Aggression Scale (Stanford et al, 2003) | Self-Report Mood scale | Personality/Mood | <ul style="list-style-type: none"> • Impulsive aggression • Premeditated aggression |
| The Momentary Impulsivity Scale (Tomko et al., 2014) | Self-Report Mood scale | Personality/Mood | <ul style="list-style-type: none"> • Said without thinking • Impatient • Spent money • Spur of the moment |
| Assessing Mood in Daily Life (Wilhelm & Schoebi, 2007) | Self-Report Mood scale | Personality/Mood | <ul style="list-style-type: none"> • Valence • Energetic arousal • Calmness |
| Cued go no-go task (Marczinski & Fillmore, 2003) | Computer Task | Behavioural | <ul style="list-style-type: none"> • Reaction Times • Error Rates |
| Marshmallow test (Walter, Ebbe & Antonette, 1972). | Food Reward | Behavioural | <ul style="list-style-type: none"> • Delay discounting |
| Delay discounting (Mazur, 1987) | Various | Behavioural | <ul style="list-style-type: none"> • Delayed rewards |
| The Balloon Analogue Risk Task (Lejuez et al., 2002) | Computer Task | Behavioural | <ul style="list-style-type: none"> • Reaction Times • Error Rates • Behavioural inhibition |

| Measure | Type of Measure | Theoretical perspective | Test Dimensions |
|--------------------------------------------------------------------------------|-------------------------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Immediate and Delayed Memory Task (Dougherty, Marsh, & Mathias, 2002) | Computer Task | Behavioural | <ul style="list-style-type: none"> • Correct Detections • Commission Error • Filler Errors • Distracter Errors |
| Iowa gambling task (Bechara et al., 1994) | Various | Behavioural | <ul style="list-style-type: none"> • Risky decision making |
| Differential Reinforcement of Low Response Rate Task (Ferster & Skinner, 1957) | Food Reward | Behavioural | <ul style="list-style-type: none"> • Behavioural inhibition |
| EEG | Brain Imaging Technique | Neurological | <ul style="list-style-type: none"> • Brain wave band • Local electrical activity |

2.12 Personality/Mood Measures

The Barratt Impulsiveness Scale (BIS-11; Patton *et al.*, 1995)

Is one of the most widely used and accepted questionnaire which measures the personality/behavioural constructs of impulsiveness. It has been used to advance the understanding of this construct for 50 years (Stanford *et al.*, 2009).

Patton *et al.* (1995) define the current 11th version of the instrument and was achieved by a principal components analysis on BIS-11 scores gathered from a sample of 248 psychiatric inpatients and 412 university students. Factor analyses from data highlighted several first and second order factors yielded from the 30 items in the scale see table 6.

Table 6: First and second order factors of the Barratt Impulsiveness Scale 11.

| Barratt Impulsiveness Scale 11 – Factor Structure and Scoring | | | |
|---------------------------------------------------------------|-----------------------|------------|-------------------------------------|
| 2nd Order Factors | 1st Order Factors | # of items | Items contributing to each subscale |
| Attentional | Attention | 5 | 5, 9*, 11, 20*, 28 |
| | Cognitive Instability | 3 | 6, 24, 26 |
| Motor | Motor | 7 | 2, 3, 4, 17, 19, 22, 25 |
| | Perseverance | 4 | 16, 21, 23, 30* |
| Nonplanning | Self-Control | 6 | 1*, 7*, 8*, 12*, 13*, 14 |
| | Cognitive Complexity | 5 | 10*, 15*, 18, 27, 29* |
| | | | *reverse scored items |

The Eysenck Impulsiveness Scale (Eysenck *et al.*, 1985)

The Eysenck Impulsiveness Scale (EIS) contains 54 yes/no questionnaire to assess impulsiveness. This results in measuring levels of three subscales: impulsiveness, venturesomeness, and empathy. The questionnaire was constructed through factor analysis to be highly loaded towards impulsiveness and venturesomeness. It has been widely used and well-validated measure (see Dean, 2006 for a review).

Sensation Seeking Scale (Zuckerman *et al.*, 1964)

The Sensation Seeking Scale is one of the standard psychological instrument for measuring sensation seeking. Its aim is to better understand personality traits such as: neuroticism, antisocial behaviour, and psychopathy (Arnett, 1993). There have been several updates the most recent being the 1978 version: SSS-V. There are 4 subscale in the 40 item assessment (10 in each subscale): Thrill and Adventure

Seeking (TAS), Disinhibition (Dis), Experience Seeking (ES), and Boredom Susceptibility (BS).

This scale has been implemented in a variety of research areas, specifically in adolescence. It has a reliable track record of being used in relation to impulsive pathologies, these studies include how likely students are to play drinking games (Johnson & Cropsey, 2000), Condom use during sex (Noar *et al.*, 2006) and the likelihood of drug use and gambling (Satinder & Black, 1984).

The UPPS Impulsive Behavior Scale (Whiteside & Lynam, 2001)

The UPPS is a 45-item self-report questionnaire based on the four-factor model of personality traits thought to be associated with behavioural patterns of impulsivity. These consist of urgency, lack of premeditation, lack of perseverance, and sensation seeking. Each factor is assessed with 1012 items unique to that factor. Participants respond using a 4-point Likert scale ranging from 1 (strongly disagree) to 4 (strongly agree).

Lifetime History of Impulsive Behaviors (Schmidt, 2000)

Lifetime History of Impulsive Behaviours consists of a 53-item questionnaire which identifies lifetime history of impulsive behaviours and the associated levels of distress and impairment associated caused by these behaviours. It measures six dimensions: impulsivity, sensation seeking, trait anxiety, state depression, empathy and social desirability. While also categorising impulsivity into: clinically significant impulsivity, non-clinically significant impulsivity, and impulsivity related distress/impairment (McCloskey *et al.*, 2009) . Although this tests temporal scope is large; participants may fail to recall relevant traumatic or repressed events.

Dickman Impulsivity Inventory (Dickman, 1990)

The Dickman Impulsivity Inventory proposes that there are two types of impulsivity functional impulsivity and dysfunctional. The scale includes 63 items of which 23 are related to dysfunctional impulsivity, 17 are related to functional impulsivity, and 23 are filler questions that relate to neither construct Burnett (2012). The scale has also been converted to a version for use with children Brunas-Wagstaff, (1997) as well as translated into several languages. As far as intern validity of the two concepts measure, there is no correlation between these two tendencies across individuals, and they also have different cognitive correlates (Dickman, 1990).

Inhibition System/Behavioural Activation System (Carver, 1994)

Behavioural Inhibition System/Behavioural Activation System (BIS/BAS) was developed based on the biopsychological theory of personality (Gray, 1981). It suggests that there are two general motivational systems that underlie behaviour and affect: (BAS) is believed to regulate appetitive motives, behavioural avoidance (or inhibition) system (BIS) is said to regulate aversive motives. This 20-item self-report agree/disagree questionnaire is designed to assess dispositional BAS and BIS sensitivities. Impulsivity is associated with high BAS and low BIS scores.

Impulsive/Premeditated Aggression Scale (Stanford *et al.*, 2003)

The Impulsive/Premeditated Aggression Scale (IPAS) is a 30-item self-report questionnaire. Fifteen items assess impulsive aggression and 15 describe premeditated aggression. Aggressive behaviour can be classified as either impulsive or premeditated. Impulsive aggression is caused by a momentary loss of behavioural control, whereas premeditated aggression is a planned or conscious act. The IPAS differentiates between these concepts. Post evaluation of subjects who have taken this scale show that those with impulsive factors have a broad range of emotional

and cognitive impairments. Subjects scoring highly on premeditated factor showed greater inclination for aggression and antisocial behaviour (Stanford *et al.*, 2003).

The Momentary Impulsivity Scale (Tomko *et al.*, 2014)

The Momentary Impulsivity Scale adapts Items from BIS-11 and the Structured Interview for Personality Diagnostic and Statistical Manual of Mental Disorders IV (SIDP-IV) to reflect momentary aspects of impulsivity. Items were selected that reflect both behavioural and internal aspects of impulsivity for maximal coverage of the concept. The scale used a limited number of 9 items to reduce participant burden, which were further reduced to a brief 4-item scale for the assessment. When tested sufferers of BPD showed significantly higher scores on our Momentary Impulsivity Scale than controls. The scale was also moderately correlated with common trait impulsivity scales (Tomko *et al.*, 2014). This scale is good at testing for state dependent impulsiveness as it is short and looks at current mood.

Assessing Mood in Daily Life (Wilhelm & Schoebi, 2007)

This second state measure of mood consists of a six-item scale extracted from the Multidimensional Mood Questionnaire (MDMQ; Steyer *et al.*, 1994). The bipolar items consist of tired–awake (E+), content–discontent (V–), agitated–calm (C+), full of energy–without energy (E–)1, unwell–well (V+), relaxed–tense (C–). This measure has been designed to rapidly assess a participant's current mood.

2.13 Behavioural Measures

Laboratory behavioural measures of this complex and often misunderstood behaviour vary widely, with different measures assessing different underlying component processes.

Cued go no-go task (Marczinski & Fillmore, 2003)

Is a task where stimuli are presented in a continuous stream, participants are primed to respond in a certain way to a certain cue they then perform a binary decision on each stimulus. One of the stimuli requires participants to make a motor response (Go condition), whereas the other requires participants to withhold a response (No-go). Accuracy and reaction time are measured for each event. There is good evidence into the validity of this task in a clinical setting. ADHD suffers who are expected to show degraded impulse control display more commission errors and slower response inhibition compared with controls (Derefinko *et al.*, 2008). The test has also been used in substance abuse studies including: Cocaine, whereby showed slower learning of the associated no-go cues (Fillmore & Rush, 2006). Acute alcohol use, which inhibited responses to no-go targets worsening as alcohol intake increased (Marczinski & Fillmore, 2003) and finally orally-administered d-amphetamine increased the probability of failing to inhibit responses to no-go targets (Marczinski & Fillmore, 2003).

Marshmallow test (Walter, Ebbe & Antonette, 1972).

The marshmallow experiment originated from a series of studies on delayed gratification at Stanford University (Mischel, Shoda & Rodriguez, 1989). The task involves a choice between one small reward provided immediately or two small rewards (a greater reward) if they waited for a short period (approximately 15

minutes while the tester left the room). The reward was often food based being a: marshmallow, cookie or pretzel. In follow-up studies, it was found that the participants who were able to wait longer for the preferred rewards had better life outcomes. These were measured by means of SAT scores (Mischel, 1989), educational attainment (Ayduk *et al.*, 2000), body mass index (Schlam *et al.*, 2013) and other life measures (Shoda, Mischel & Peake, 1990). Additionally in 2011 a brain imaging study from the original Stanford participants during mid-life showed key differences between the high delay time individuals and those with low delay times in two areas: the prefrontal cortex (greater activity in high delayers) and the ventral striatum (an area linked to addictive behaviour) when they were trying to control their responses to alluring temptations (Casey *et al.*, 2011). Areas highlighted as playing a role in impulsive behaviours.

Delay discounting (Mazur, 1987)

Temporal discounting (delay discounting/time discounting/time preference) tasks investigate a tendency to give greater value to rewards things as they move from their temporal horizons, towards the present (Doyle, 2013). Although these are often monetary rewards numerous studies have attempted to measure discount rates for hypothetical health states (Asenso-Boadi, Peters & Coast, 2008), gambling problems and substance misuse (Petry & Casarella, 1999; Petry, 2001). All of which are indicative of impulsive pathologies.

The Balloon Analogue Risk Task (Lejuez *et al.*, 2002)

The Balloon Analogue Risk Task (BART) is a computerized measure of risk taking behaviour. It simulates real-world risk behaviour through a conceptual frame of balancing the potential for reward versus loss. The task consists of being presented with a balloon and offered the chance to earn money for inflating the balloon at a click of a button. Each click causes the balloon to inflate and money to be added to a

running total, the larger the balloon the more chance it will pop. Each pump carry's greater risk, but also greater potential reward. If the participant chooses to cash-out prior to the balloon exploding then they collect the money earned for that trail, but if balloon pops than the accumulated money is lost. Participants are unaware of how likely the balloon is to explode. This allows for a participants' initial responses to the task and also the speed in which they learn the task contingencies. Analyses of performance across sessions indicates a reasonably robust test-retest correlation (T1/T2 $r = .77$). It should be noted that there are modest increases in risk-taking with repeated administrations within a single day (White, Lejuez & de Wit, 2008). Although this is not a direct measure of impulsivity it provides a real world framework for behaviours associated with the concept.

Iowa gambling task (Bechara *et al.*, 1994)

The Iowa Gambling Task is a computerised task that assesses risky decision-making. The original version involves four card decks of cards, A, B, C and D. When a participant selects a card, a specified amount of play money is awarded. However amongst the rewards are also monetary loss cards. Decks A & B have high immediate financial gains, however have more monetary loss cards resulting in a lower actual yield. Whereas decks C & D have small initial monetary rewards but less monetary loss cards resulting in a higher overall yield. The aim is for participants to make as much money as possible while losing as little as possible. They can choose cards from any deck and can switch decks at any time. After 100 card choices the task ends. The best performance requires participants to learn the contingencies in each deck as the task progresses adapting their play style. This test is similar in its function as the Balloon Analogue Risk Task and helps understand the impact of impulsive tendencies in a real world environment.

Immediate and Delayed Memory Task (Dougherty, Marsh & Mathias, 2002).

The Immediate and Delayed Memory Task involves rapidly responding to a series of visual stimuli (usually a string of numbers) on a computer. A response is required when the current number matches the number immediately before it (correct detection). The Delayed Memory Task similarly involves responding to matching numbers, but the numbers to be compared is separated by a filler sequence. The task involves selectively responding target stimuli and avoiding responses to non-target stimuli that are presented in rapid sequence. Commission errors (motor impulsivity) are recorded when immediate responses are incorrect, and omission errors (attentional impulsivity) which are nonresponses to correct the stimuli. This has been found to be a stable measure across trials (Dougherty *et al.*, 2000), while also being viable when experimental manipulation of impulsive occurs (Dougherty *et al.*, 1999).

Differential Reinforcement of Low Response Rate Task (Ferster & Skinner, 1957)

The Differential Reinforcement of Low Response Rate Task requires participants to withhold a response for a specific period of time and then respond to receive a reinforcement. Responses made before the time criteria do not produce reinforcement but instead reset the trial. The subject must learn to withhold responses for a certain amount of time before their behaviour will be reinforced. This task has been used to model timing behaviour (Schuster and Zimmerman, 1961), measure response inhibition (Popke *et al.*, 2000), and impulsive behaviour (Van Den Broek *et al.*, 1987). This methodology is usually used in substance abuse studies (McClure and McMillan, 1997).

2.14 Neurological measurement and mechanisms of Impulsivity

Electroencephalography (EEG) and Functional magnetic resonance imaging or functional MRI (fMRI) are the most common brain imaging techniques used when investigating the neurological processes behind impulsivity. EEG is an electrophysiological monitoring method to record electrical activity. In the more common non-invasive methods, electrodes are placed at set positions along the scalp. Alternatively an invasive procedure places electrodes in contact with cortical regions directly (electrocorticography). EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain, it is usually of interest to monitor this electrical activity over a period of time (Niedermeyer & da Silva, 2004).

Functional magnetic resonance imaging or functional MRI (fMRI) is neuroimaging using MRI technology measures brain activity by detecting changes associated with bloodflow (Huettel, Song & McCarthy, 2009; Logothetis *et al.*, 2001). This technique utilises cerebral blood flow and neuronal activation. When an area of the brain is in use, blood flow to that region also increases allowing for a functional image of the brain (Niedermeyer & da Silva, 2004).

There have been two main tasks using brain imaging techniques to investigate the neurological pathways behind impulsivity, response inhibition and risk taking. Response inhibition tasks utilise a fronto-lateral executive system (Rubia, Smith & Taylor, 2007; Rubia *et al.*, 2006; Castellanos-Ryan, Rubia & Conrod, 2011; Garavan *et al.*, 2006; Menon *et al.*, 2001), whereas risk taking tasks use reward-related pathways (Kringelbach & Rolls, 2004; Van Leijenhorst *et al.*, 2010). There may be a slight overlap between these two neural networks; however, each has its own distinct network.

A meta-analysis of 30 response inhibition studies using fMRI imaging found that the ventrolateral prefrontal cortex, the Dorsolateral prefrontal cortex, and the dorsal Anterior cingulate cortex are vital areas involved in response inhibition (Criaud & Boulinguez, 2013). Findings of two lesion studies show that damage to the orbital frontal cortex also has an effect on behavioural disinhibition (Berlin, Rolls & Kischka,

2004) while lesions to the right inferior frontal gyrus damages leads to reduced effectiveness in stop-signal inhibition (Aron *et al.*, 2003)

This suggests that executive control mediation of motor responses is involved in the impulsivity neural network. Risky taking tasks relies on reward seeking behaviour. An extensive meta-analysis of 206 fMRI studies proposes that reward activate a valuation pathway including the ventro-medial prefrontal cortex, the ventral anterior cingulate cortex, and the ventral striatum (Bartra, McGuire & Kable, 2013). This notion has also been supported by recent fMRI studies which highlight the pivotal role of these regions in risky decision-making (Bogg *et al.*, 2012; Rao *et al.*, 2010; Schonberg *et al.*, 2012). Furthermore, damage to the ventromedial frontal cortex results in patients showing poor decision-making and taking higher risk in the Iowa Gambling Task (Bechara *et al.*, 1996; 1999)

In brief there is a large amount of evidence that cognitive control involves fronto-lateral mechanisms (Castellanos-Ryan, Rubia & Conrod, 2011) and risk taking behaviours rely on reward-related structures (Glascher *et al.*, 2012; Noonan *et al.*, 2010).

Using EEG techniques has been pivotal in gaining an understanding of impulsivity neural pathways. The implementation of frontal EEG asymmetry was a turning point in EEG research (Coan & Allen, 2004). Impulsive states have been characterised by anterior asymmetry (Davidson, 1988; Davidson *et al.*, 1985, 1990), a phenomenon whereby there is proportionally more activity in one cerebral hemisphere than the other. Additionally Hewig *et al.* (2004) found that in university students, participants with greater bilateral frontal cortical activity displayed higher behavioural activation scores.

There are predominantly four main rhythms of brain waves that determine an individual's state: Delta (<4 Hz), theta (4-8 Hz), alpha (8-14 Hz) and beta (14-40 Hz) (Cahn, Rael & Polich, 2006).

Alpha rhythm is a pattern that is present in awake adults who are relaxed with their eyes closed. These have the greatest strength in the occipital and parietal regions of the cerebral cortex (Feshchenko *et al.*, 2001). Beta waves are formed in individuals who are alert and attentive to external stimuli or exert specific mental effort and

during REM (rapid eye movement) sleep. These waves are associated with cortical arousal, a higher state of alertness and memory retrieval (Pfurtscheller & Lopes da Silva, 1999). Delta and Theta waves are low-frequency patterns that increase during sleep both may present themselves during wakefulness, Theta in emotional responses and Delta during difficult mental activities requiring concentration (Manni, 2005).

A variety of EEG studies have investigated brain wave differences to understand impulsivity. One of the ways this has been examined is through the difference in ratio between theta/beta waves and inhibitory control. A Low theta/Beta ratio resulted in longer stopping reaction times in 'healthy' individuals. Thus the authors proposed a higher theta/beta ratios reflect reduced cortical inhibition over subcortical input, resulting in greater inhibition related performance (Lansbergen, Schutter & Kenemans, 2007).

Spectral power studies using qEEG and computer-aided signal analysis have consistently found that impulsive pathologies have increased EEG power in delta, theta and beta bands. Increases in delta activity is conducive of criminal and or violent behaviour (Fishbein *et al.*, 1984; Reyes & Amador, 2009), Bipolar Disorder (Philipsen, 2005), ADHD (Matsuura *et al.*, 1993), methamphetamine dependence (Newton *et al.*, 2003), MDMA use (Herning *et al.*, 2005), and paraphilia (Flor-Henry *et al.*, 1991). Increased theta power has been found in similar impulsive based behaviours: violent crime (Reyes & Amador, 2009), ADHD (Mann *et al.*, 1992), alcohol dependence (Pollock *et al.*, 1992), methamphetamine dependence (Newton *et al.*, 2003), and paraphilia (Flor-Henry, Lang, Koles & Frenzel, 1991). These findings would further indicate that suggest that impulsive states are the result of excessive low frequency activity.

Antagonistically decreases in delta activity result in greater cortical activity and alertness (Knott & Harr, 1996) with suppressed theta band waves associated with hypervigilance and attention (Beatty *et al.*, 1974). It has also been demonstrated that participants that score highly in self-report measures of impulsivity show greater slow wave activity (Barratt & Patton, 1983). The majority of impulsive pathologies

are associated with increased slow wave activity, suggesting they share the same underlying mechanism. This could be explained by low cortical arousal, a notion supported by Barratt (1985). When analysing high frequency EEG activity, individuals suffering from impulsive related pathologies exhibited increases in beta activity (Pollock *et al.*, 1992; Newton *et al.*, 2003; Flor-Henry *et al.*, 1991; Koelsch *et al.*, 2008) apart from in the case of ADHD sufferers. Beta band frequency can be used to quantify cortical arousal, with high levels resulting in hyper-excitability in the central nervous system (Rangaswamy *et al.*, 2002). Thus impulsive pathologies with increased beta activity may be caused by an imbalance of inhibition-excitation in the central nervous system.

2.15 The Effect of Colour on Impulsivity

Case studies have previously suggested that blue reduces impulsiveness (see Table 1) although these have not supported by appropriate studies. There is very little research to directly link colour and impulsivity, reaffirming the need for more work in this area. Zentall, Falkenberg and Smith (1985) conducted a study on adolescence with hyperactivity. The findings showed that attention-problem adolescents performed better with high-stimulation task (which included the presence of colour) stimuli than with low, relative to the opposite performance pattern of controls. Further research was conducted to reaffirm the hypothesis that non-relevant colour stimulation normalises sustained attentional performance. In the follow up study, Zentall & Anne (1989) tested if colour improved the performance of subjects on an impulsivity task. It was found that adding non-relevant colour in the task normalised the activity of hyperactive children. Hyperactive children also responded slower on tasks where stimuli contained colour in addition to black, relative to controls.

There has however been recent work by Duan (2017) which investigates the direct links between colour, impulsivity, arousal and emotion. Using computer based tasks, questionnaires and psychophysical measurements it was discovered that there was

indeed an effect between colour and impulsiveness: Hue had more of an effect on arousal than impulsivity, purple and red increased levels; while yellow, blue and green reduced them. Antagonistically yellow increased impulsiveness and red reduced it, this effect was stronger in females than male. Chroma had the largest effect on impulsiveness, there was a clear trend of red and orange increasing impulsivity, with more intense chroma level having the stronger effect. Generally it was reported that warm colours are more impulsive and arousing than cool colours; however, most colours made participants react with more errors than average on a Rotation Test.

Colours Psychology.

Given the prevalence of colour in the environment, colour psychology has historically been an undeveloped area. The research that has been conducted often relies more on practical concerns, and not based on empirical evidence. This has resulted in many conflicting findings and with no clear conclusions about colour (Levy, 1984; Whitfield & Wiltshire, 1990). A model of colour and psychological functioning, has recently been developed to combat this issue which sets out a 6 point framework (Elliot & Maier, 2007).

1. Colour is not purely for aesthetics, it is a stimuli that contains more information.
2. Colour meaning is derived from two basic sources: learned associations through reinforcement and biological processes.

Some colour associations may emerge from repeated priming, but it is argued that evolutionarily ingrained responses are more likely (Mollon, 1989).

Within the animal kingdom colours are signal function (ripeness of fruit or to indicate toxicity) facilitating fitness-relevant behaviour (Hutchings, 1997). Therefore humans may respond subconsciously in a similar way.

3. Colour evokes evaluative processes.

As discussed earlier colour processing occurs early within the visual system, and evaluative processes are so fundamental (Schneirla, 1959). This evaluation is a defensive mechanism which differentiates between a stimulus being hostile or hospitable (Elliot & Covington, 2001).

4. The evaluation processes evoked by colour results in either a positive or negative response.

Colour stimuli carrying a positive meaning result in an approach responses, whereas a negative meaning produce avoidance responses (Wentura, Rothermund & Bak, 2000).

5. Colour exerts its influence on psychological functioning in an automatic fashion.

The process of evaluating a colour stimulus to the subsequent behaviour typically takes place without conscious awareness. (Olsen, 2010).

6. Colour meanings and effects are contextual.

Colours have different implications for feelings, thoughts, and behaviours in different contexts.

Colour and arousal

As discussed earlier, there are two main paradigms used when explaining the neurologically arousing effect of colour. The process is either; a learned or associated response (Grossman & Wisenblit, 1999) or the result of the activation of an internally innate mechanism (Hupka *et al.*, 1997).

An associative response to colour is caused by past experiences which have an effect on an individual's physiological arousal, a process known as 'associative learning'. An unpleasant (fear) stimulus could be paired to a particular colour for example red with blood and pain. After several similar associations future exposures to that colour elicits the same neurological response to the paired stimulus but with only the colour being present (Bierley, McSweeney & Vannieuwkerk, 1985).

A wealth of research has been conducted into the effect of colour on arousal (see below). The general consensus is that the effect of the colour is dependent on its wavelength. Longer wavelength light (yellow, orange and red) result in greater neuronal activation whereas shorter wavelengths (green and blue) have a sedative effect (Wright & Rainwater, 1962).

Projections of red light on a white screen in-front of participants caused increases in cortical arousal and palmer conductivity. In contrast to the blue light (short wavelength) condition whereby both of these measures were significantly lower. Additionally to these two changes, blood pressure, respiratory rate and eye-blink frequency were all lowered under blue light while increased in red light in comparison to the white light control. The one measured variable which was unaffected throughout the trials was heart rate (Gerard, 1958). As well as unconscious changes in arousal there has also been reported a conscious effect which varied in each light condition. The study used word association to measure this effect. Reds have associations with words like exciting, stimulating, and powerful compared to blue which had links with words such as peaceful, calm and gentle (Wexner, 1954). A factor analysis of these words by Wright and Rainwater (1962) found significant interrelationships between clusters of colours and associated words which were similar to those found in the Wexner study.

Some more biological based studies have investigated the physiological effect of colour. Kosslyn (2003) studied light exposure and the consequential hormone release from glandular activity was measured. The most activity was seen in the presence of red light, activation and secretion of hormones from the pituitary gland was observed. Pituitary gland stimulation results in activation of the adrenal medulla releasing epinephrine. This is a quick acting hormone which 'increases neuronal activation, causing a higher psychological state with peaked behaviour and emotional responses' (Fuller, 1982). A similar study measuring biological responses associated with colour exposure measured skin conductivity (a traditionally more accepted indicator of arousal). During the experiment participants were placed in an environment which was flooded with either red or green light. Red caused increases

in skin conductivity. In addition to the measurement of skin conductivity participants were asked to describe how they felt when in each of the conditions. When immersed in red light it was largely reported that there was more of a feeling of stimulation and excitement, supporting the concept that longer wave length colours cause more arousal presented as physiological responses (Wilson, 1966). Yoto (2007) illustrated the arousing properties of colour on brain activity through the use of object coloured stimuli and measurements of electroencephalogram (EEG) alpha band response and blood pressure. Participants were exposed to three randomised condition's three test conditions (red, green or blue sheets). They then filled out a questionnaire to assess any psychological effects. Different colours caused different effects, a change in the mean power of alpha band, theta band, and total theta-beta EEG bandwidth in addition to alpha attenuation coefficient (AAC) was observed. Blue caused the greatest arousal in the AAC and in the mean power of alpha bands, contrary to results from the questionnaire. However, "alpha band, and the theta band, and the total power of the theta-beta bandwidth as measured by EEG showed larger values while the subjects looked at red paper than while they looked at blue paper". This suggests that red caused higher brain activity and thus a higher state of anxiety and arousal.

Exposure to colour has also had a marked physical effect, it has been demonstrated that it can affect task performance during a fine motor movement and hand-eye coordination task (wire loop game). Participant responses changed depending on the colour of the structure which surrounded the task. During the red condition and in support of other findings in this area (higher levels of arousal when exposed to red) the task completion times were on average faster than in any of the other coloured conditions. There was however more errors due to an increased amount of hand shaking (Nakshian, 1964). A study comparing the results of three experiments investigated the psychological and physiological arousing effects of room interiors (Küller, 2009). It was found that grey, blue and red patterned coloured interiors had an effect on both the emotions and physiology of participants residing within it. This effect was pronounced especially within the red and patterned room which "put the brain into a more excited state". Valdez (1994) presented some contradictory

evidence that “green-yellow, blue-green, and green were the most arousing, whereas purple-blue and yellow-red were the least arousing.”

Finally the main conclusions of a critical review containing a meta-analysis of studies by Kaiser (1984) found that:

- Red light has a positive effect on instances of epileptic seizures (wearing glasses that reduce long wavelengths reversed this).
- Galvanic skin responses show variation between colour exposures. A process mediated by sweating caused by emotionally arousing brain activation (research in this area, however, was not fully conclusive).
- Data on colours effect on blood pressure, respiration, and heart rate are inconclusive.
- One study shows a link between eye blink frequencies and colour exposure, with red causing the most and blue the least however these findings are yet to be replication.
- Foundation research on the physiological responses to colour still needs to be done in an area of study which has not been active recently.

Collectively this body of research supports the concept that red light causes increases in arousal and that blue decreases it.

The psychological effects of white light on mood has shown mixed results. Some studies have found no significant direct effect but significant indirect measurements of mood, e.g. improved willingness to participate in future experiments under warm light (3000K) (Baron, Rea & Daniels, 1992; Knez, 2001) whereas other studies showed that under longer exposure times females’ negative mood decreased under warmer light conditions (3000K) and increased under cooler light conditions (4000K); with the opposite effect on males (Knez, 1995).

Recent research has investigated non-visual influences of light on basic biological and psychological mechanisms. Chrono-biological studies have indicated a light sensitive endogenous circadian clock exists that is regulated through melatonin secretion (Lewy *et al.*, 1980; Arendt & Broadway, 1987) and skin light transduction (Campbell & Murphy, 1998). Seasonal light change and circadian desynchronization through

artificial lighting environments cause a number of disorders including depression, S.A.D (seasonal affective disorder) and insomnia, through the deepening understanding of the underlying mechanism involved in light exposure light therapy can now be used to treat these disorders (Dalglish *et al.*, 1996; Lam *et al.*, 1989).

Impulsivity & Arousal

The most basic theory which links impulsivity and arousal is known as being a one-dimensional concept. This discusses the pathways of information through the Reticular Activating System. This system describes a sensory information flow along a path which includes the reticular formation (RF) along with cortical, thalamic and hypothalamic brain regions (Boucsein, 1992; 1997). Boucsein's theory suggested that all activation caused by sensory and/or motor nerve fibres raised a general state of arousal in the RF. Neural pathways from the RF are connected to a large proportion of the central nervous system, which means that the RF has the ability to govern a general level of arousal and reactivity. This arousal is linked to physical manifestations of central nervous system arousal such as EEG, heart rate, blood pressure and EDA (electrodermal activity). There has, however, been some contradictory empirical to this which has led to the development of a more complex model (Eysenck, 1982; LeDoux, 1998).

Compared to the previous one-dimensional structure of the Reticular Activating System the new model is based on neurophysiological evidence and consists of three-dimensions: The first system echoes the concepts proposed by the one-dimensional approach. The second introduces an "affect arousal" system which comprises of emotional components of arousal governed by the amygdala, attention, orienting reflex and hypothalamic reactions. These components have an effect on the physiological processes such as spontaneous electro-dermal frequency (tonic) and cardiac change (phasic) both of which affect behaviour such as behavioural inhibition.

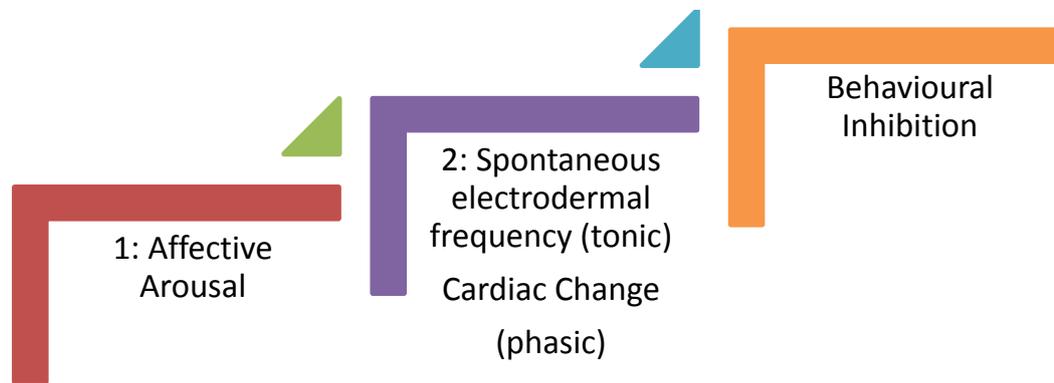


Figure 23: Extract from the three-dimensional arousal model (Boucsein, 1997).

It is stated by personality theory that impulsivity is caused by a rebound effect associated with physiological under-arousal (Barratt, 1985; Eysenck, 1993; Eysenck & Eysenck, 1985; Humphreys, 1984; Revelle, 1980). This occurs due to sharper increases in arousal when an individual with a low aroused resting state is stimulated (Carrillo-do-la-Pen, 1993; Eysenck & Eysenck, 1985; Houston, 2001). There is evidence from electro-cortical techniques (EEG, augmenting- reducing ERPs) in support of this theory; in particular there is evidence from electroencephalogram studies which show a slowing and reduction in amplitude of P300 event-related potentials in school pupils (Mathias 1998; Mathias, 1999) and prisoners (Barratt *et al.*, 1997) cohorts whom score highly on a self-reported impulsivity questionnaires (Barratt Impulsiveness Scale). There is a large amount of support from electro-cortical studies investigating the links between physiological arousal and impulsivity (Carrillo-do-la-Pen, 1993; Houston, 2001), with very few contradictions (O’Gorman, 1987). However, the majority of these studies have been conducted on ‘impulsive aggressive samples’, this means that there could be other extraneous factors such as irritability or hostility which may have a mediating effect on physiological arousal.

Autonomic measures of impulsivity have also been investigated including heart rate. This has been found to have a sensitivity in distinctions between clinical and control psychophysiological functions (Dykman, 1992). Additionally it has been used in the indexing of arousal levels (Blatt, 1961; Raine, 1987). There have been several reported studies measuring the relationship between heart rate and measures of

impulsivity. It has been reported that there is a positive correlation between heart rate variations and impulsivity (Mathias & Stanford, 2003). This correlation was notably stronger when performing 'a choice decision procedure' (Rule, 1970). Additionally a study has found that 'average heart rate has had indirect links relating to impulsivity scores through association with behaviour rating scale performance' (Raine & Jones, 1987). This concept has been given support by a recent study contain two groups of participants; one group with low resting arousal and one group with high resting arousal (determined by the results of a Barratt Impulsiveness Scale). Highly impulsive subjects were found to have a generally slower heart rate in the rest condition but also a greater reactivity in a challenging situation, which is consistent with the under-arousal theory of impulsivity (Mathias, 2003) Neural activity has been recorded in research that analysed the brain pathways associated with behavioural arousal and inhibitory control relating to individual differences in impulsivity. An fMRI machine was used to measure the brain activity of a group of healthy adults. Impulsivity had a "positive correlation with activation (arousal) in the bilateral ventral amygdala, parahippocampal gyrus, dorsal anterior cingulate gyrus (BA 32), and bilateral caudate". In addition to this there was a negative correlation when activation was seen in "the dorsal amygdala and ventral prefrontal cortex (BA 47)". This suggests that impulsivity is indeed influenced by the level of corticolimbic arousal (Brown, 2006).

Interestingly an effect has been found in relation to physiological arousal and impulse buying. A stimulating store environment was found to cause a momentary loss of self-control increasing instances of impulse purchases (Mattila & Wirtz, 2008). These findings are consistent with psychology studies which highlight that over-stimulation or high arousal lessens a person's self-regulation (Baumeister *et al.*, 1998). The use of electro cortical and electro dermal techniques in conjunction with personality measures and brain imaging techniques has advanced our understanding of the underlying neural anatomy involved in arousal and impulsivity.

3. Methodology

3.1 Multifaceted Approach

After exploring the available literature it is clear that the study of impulsivity, specifically the effect of colour on this concept is in its infancy. Therefore in an effort to maximise the scope and understanding of this relationship a multifaceted approach (see figure 24) has been implemented through the experimental stage of this research. This will include personality, behavioural and neurological perspectives. Each of these approaches have their own methodology bringing advantages and disadvantages.

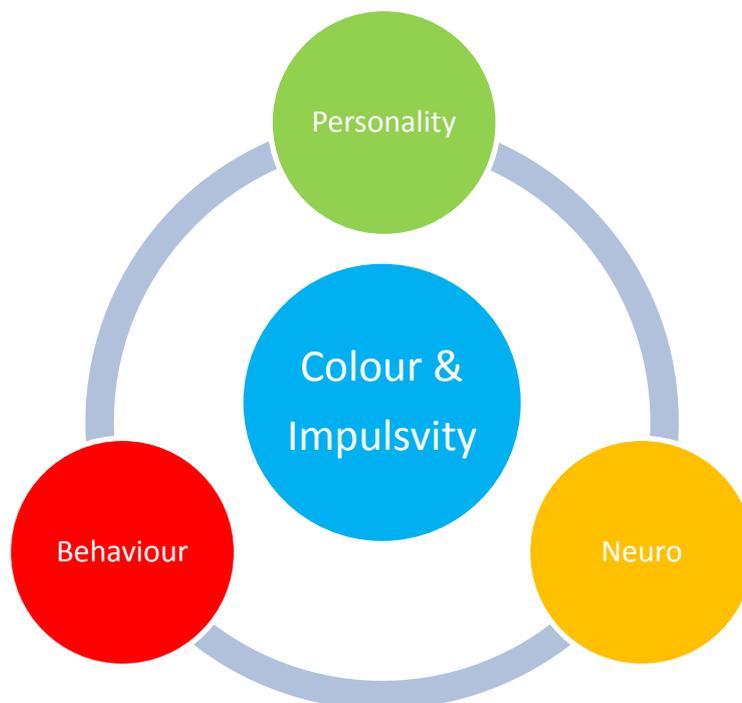


Figure 24: Multifaceted approach.

Utilising multiple methods has been shown to improve construct validity and accuracy of data (Winnie & Gittinger, 1973). In an effort to achieve this multiple theoretical schemes will be used to interpret the phenomenon using more than one

method to gather data. The virtues of taking such an approach have been highlighted when investigating the effectiveness of self-reports, peer reports, and behavioural studies regarding personality characteristics. Moskowitz (1986) found that no single method was best and that different methods should be applied to gain a more complete understanding.

3.2 Personality

Personality refers to 'the pattern of thoughts, feelings, social adjustments, and behaviours consistently exhibited over time that strongly influences one's expectations, self-perceptions, values, and attitudes. It also predicts human reactions to other people, problems, and stress' (Winnie & Gittinger, 1973). Therefore this perspective studies personality and its variation among individuals in an aim to: Understand an individual and their major psychological processes, identify individual psychological differences and understand the psychological similarities between people.

The main method used in personality studies is through objective self-reports and direct questioning for information relating to the personality construct in question (Schwarz, 1999). This can be seen in methodological trends in publications, 98% of the studies assessing personality traits in the Journal of Research in Personality in 2003 used self-report measures (Vazire, 2006) and 95% of published studies in the Journal of Personality (2006) used self-report questionnaires (Kagan, 2007). The benefits of using this methodology are clear, a large amount of information spanning a long period of time can be conveyed relatively easily through ongoing thoughts, feelings and actions relayed through self-expression (McCrae & Costa, 1999). Introspection also exposes details that observation alone would not capture. Questionnaires are relatively quick and cost effective forms of gathering information requiring little specialist knowledge to administer. However, care should be taken as the structure of the questions can easily effect if participants report information accurately or if the construct in question is probed successfully. Self-report is

particularly susceptible to response biases and socially desirable responding (Paulhus, 1991) There is also the possibility that participant’s self-perceptions are unrealistic and/or incomplete in important areas of the concept being measured (Fiske & Taylor, 1991; Kagan, 1988).

Four questionnaires have been selected to measure impulsivity during this research. The Barratt Impulsiveness Scale measures trait impulsivity while three measures identify state impulsivity: The State Impulsivity Scale (SIS), The Momentary Impulsivity Scale & Assessing Mood in Daily Life (see appendix A).

Questionnaire 1: Barratt Impulsiveness Scale (BIS 11)

It is the most widely cited questionnaire for the assessment of impulsiveness and has been used to advance the understanding of this construct and its relationship to other clinical phenomena for 50 years (Stanford *et al.*, 2009) The current version (11) consists of 30 items describing common impulsive or non-impulsive (for reverse scored items) behaviours and preferences (see table 7). Items are scored on a 4-point scale from: Rarely/Never = 1, Occasionally = 2, Often = 3 to Almost Always/Always = 4.

Table 7: Barratt Impulsiveness Scale 11 – Factor Structure and Scoring

| 2nd Order Factors | 1st Order Factors | # of items | Items contributing to each subscale |
|-------------------|-----------------------|------------|-------------------------------------|
| Attentional | Attention | 5 | 5, 9*, 11, 20*, 28 |
| | Cognitive Instability | 3 | 6, 24, 26 |
| Motor | Motor | 7 | 2, 3, 4, 17, 19, 22, 25 |
| | Perseverance | 4 | 16, 21, 23, 30* |
| Nonplanning | Self-Control | 6 | 1*, 7*, 8*, 12*, 13*, 14 |
| | Cognitive Complexity | 5 | 10*, 15*, 18, 27, 29* |

*Reversed scored questions

Questionnaire 2: State Impulsivity Scale (SIS)

The SIS evaluates impulsivity as a manifested behaviour which fluctuates in the short-term. This is achieved through a 20-item scale evaluating participant's frequency of behaviour from: almost Never, sometimes, quite often, to almost always/always. A factorial analysis of the SIS identified that the items are distributed based on the theoretical model for each subscale: Reward (the urge to satisfy an impulse), preference for immediate rewards, intolerance to frustration and acting regardless of negative consequences (García-de Cecilia & Rubio-Valladolid, 2011).

Questionnaire 3: The Momentary Impulsivity Scale (MIS; state)

This questionnaire is designed to assess impulsivity in daily life. It provides both between-individual and within-individual information using a brief 4-item scale:

1. I say things without thinking.
2. I spend more money than I mean to.
3. I have feel impatient.
4. I make "spur of the moment" decisions

It capture aspects of both the BIS-11 motor non-planning (questions 1 & 2) and attentional (question 3) impulsivity subscale. In addition to this, the MIS total score correlates with the majority of subscales from the UPPS: Urgency, Lack of Premeditation, and Lack of Perseverance.

The MIS is less likely to be affected by memory heuristics or biases that affect validity (or accuracy) of trait self-reporting as the questions concern immediate or very recent mood, thoughts, and behaviour. Therefore results from this questionnaire are most likely to evaluate physiological and biological processes of the state as opposed to retrospective or trait self-reports (Conner & Barrett, 2012).

Questionnaire 4: Assessing Mood in Daily Life (state)

This measure evaluates mood using a six-item scale designed for momentary assessment in daily life. It measures three basic dimensions of mood: valence (V), calmness (C), and energetic arousal (E). Participants are asked to circle appropriately how they currently feel between two bipolar concepts (e.g. Awake 5-4-3-2-1-0-1-2-3-4-5 Tired). Although there is no direct measure of impulsiveness, this scale identifies some closely related concepts, which when combined with other impulsivity measures can give a more complete picture of a participant's state within each condition.

3.3 Behavioural

Behaviourism understands humans through the systematic study of their behaviour. It assumes that behaviours are either reflexes resulting from certain environmental stimuli or in response to reinforcement and punishment learnt over time. The main technique of data collection is through observation of how a participant responds to a given situation or stimulus.

Although; behaviour can be manipulated by an individual and still suffers from the same response biases in personality data collection techniques (e.g. attempting to appease the observer; Moskowitz, 1986). It does allow for good assessment of how a person presents situation-specific traits and avoids the risk of recall error when assessing behaviours retrospectively (Henry *et al.*, 1994). Another consideration should be the ecological validity of the behavioural tests observed. Within a laboratory environment the confounding variables and environment can be controlled but this may make an artificially situation meaning results may only be valid for factors in that situation rather than being dispositional (Furr and Funder, 2007).

Task 1: Cued go no-go task (Marczinski & Fillmore, 2003)

This task measures how much impulse control a participant possess by analysing the ability an individual has to inhibit instigated, “prepotent” responses. The task manipulates this by presenting a preliminary go or no-go cue before the actual go or no-go target is displayed (see figure 25). The cue therefore provides information of the probability that a go or no-go target will be presented. The cue-target relationship is manipulated so that the cues have a high probability of correctly signalling a go or no-go target (valid cues), and a low probability of incorrectly signalling a target (invalid cues). The vertical cue indicates a high probability of a go signal with a go / no-go ratio of 4:1 (80% go trials, 20% no-go trials). Whereas a horizontal cue means there is a higher probability of no go trials with a go / no-go ratio of 1:4 (20% go trials, 80% no-go trials).

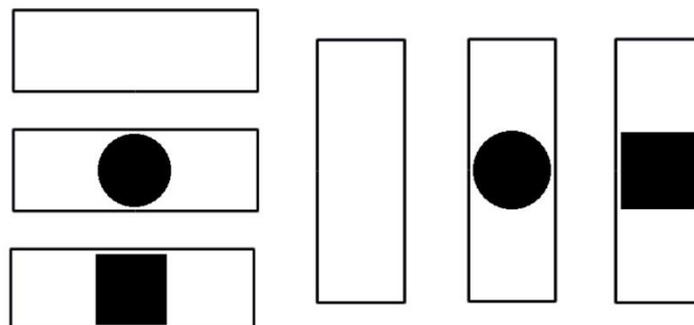


Figure 25: Example of the Cues used in go no-go task.

A fixation point is displayed for 800 milliseconds (ms) then after 500ms a cue is presented (A rectangle at different orientations) which signals to the participant of the expected go target (A black circle). The go target is then presented, the subject responds by pressing the space bar computer key. The trial times out after 1000ms which is then followed by a 700ms interval before the next trial starts. The data collected records the accuracy and speed of the response. (Fillmore & Weafer, 2013).

Task 2: The Balloon Analogue Risk Task (BART; Lejuez *et al.*, 2002)

This is a computerized measure of risk taking behaviour. The BART models real-world risk behaviour through the conceptual framework of balancing the potential for reward versus loss. In the task, the participant is presented with a set of 10 decolourised balloons (see figure 26) and offered the chance to earn money by pumping the balloon up by clicking a button. Each click causes the balloon to incrementally inflate and money to be added to a counter, the more inflated the balloon the higher probability the balloon may explode with the next pump. Thus, each pump confers greater risk, but also greater potential reward. The participant may 'cash out' their balloon as long as it hasn't popped at which point they lose all monetary value from that balloon. Pump rate, average amount of pumps and number of exploded balloons are recorded.



Figure 26: Example of the BART balloon image.

3.4 EEG

Neuropsychology investigates the structure and function of brain areas in relation to psychological processes and behaviours. It is a largely experimental field of psychology that aims to understand how behaviour and cognition are influenced by brain functioning. It has predominantly been used to diagnosis and treat the behavioural and cognitive effects of neurological disorders. The vast majority of neuropsychology methodologies were not designed to predict how participants function in real-world settings.

The most common brain imaging techniques are brain imaging studies and impulsivity are EGG. The biggest advantages of EEG is its good temporal resolution; the ability to see brain activity as it unfolds in real time in milliseconds. The disadvantages are of poor spatial resolutions (being able to identify the exact position and subsequent brain region of activity). However, it can be a useful tool for detecting general brain wave states.

The School of design uses the B-Alert X10 EEG Headset System EEG system (see figure 27). This is a portable 9-channel combination of mid-line and lateral EEG sites (positions Fz, F3, F4, Cz, C3, C4, POz, P3, P4 see Figure 28) which also has additional channels for ECG, EMG, or EOG data. General brain wave information will be collected as well as some individual site related data.



Figure 27: B-Alert X10 EEG Headset System.

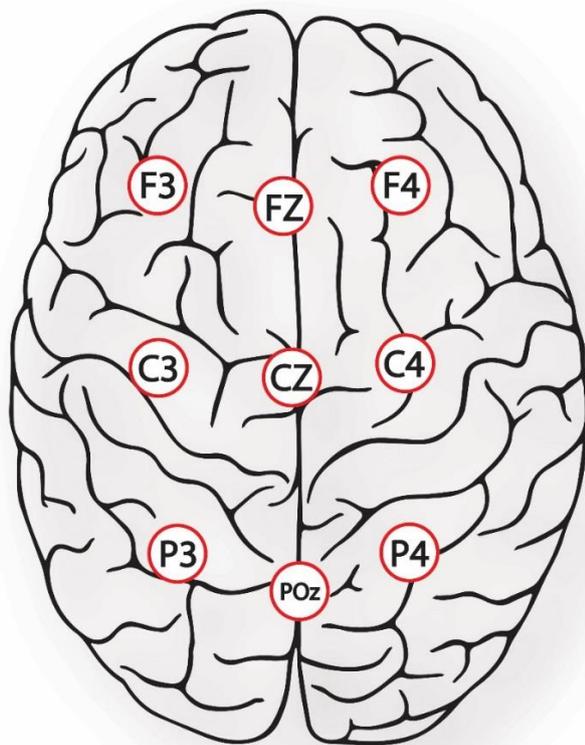


Figure 28: B-Alert X10 EEG headset system electrode sites.

3.5 Coloured environment

A controlled colour environment was created for this study using a THOUSLITE LEDCube system (Wang, 2016). Five conditions were used across each experiment: white (as a control see figure 29), red (figure 31), green (figure 33), blue (figure 35) and yellow (figure 37). The conditions are intense colours for maximal perceptual effect. It is a priority to use saturated colours to see if there is an effect present rather than to make more ecological valid environments that individuals are exposed to on a daily basis. The colours for each condition were also chosen to have a large range in CCT (from 40000 in the blue condition to 1000 in the red condition see tables 8, 9, 10, 11 & 12) while also covering a large proportion of the CIE colour space (see figure 39), this was again an attempt to encapsulate as much variation in conditions as possible within the time restraints of this study. Luminosity across all conditions was observed to be within 40 cd/m² of the control. The spectral composition of the conditions were also captured (figure 30, 32, 34, 36 & 38). This is particularly important when identifying which retinal cells will be activated and also in reproduction of accurate spectra in future research.

White (Control) Environment



Figure 29: White environment photograph.

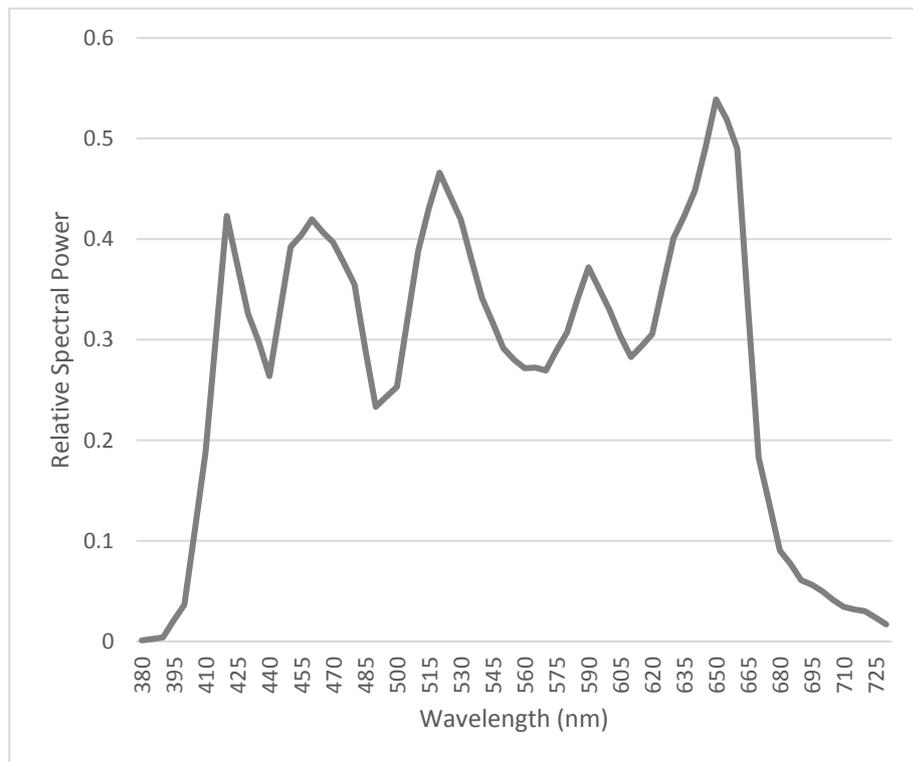


Figure 30: Spectral measurement of white environment

Table 8: Colorimeter readings of white environment

| | | |
|---------------------------|------------|------------|
| CIE | x = 0.3289 | y = 0.3295 |
| CCT | 5670 | |
| Lumi (CD/m ²) | 237.5 | |

Red Environment



Figure 31: Red environment photograph.

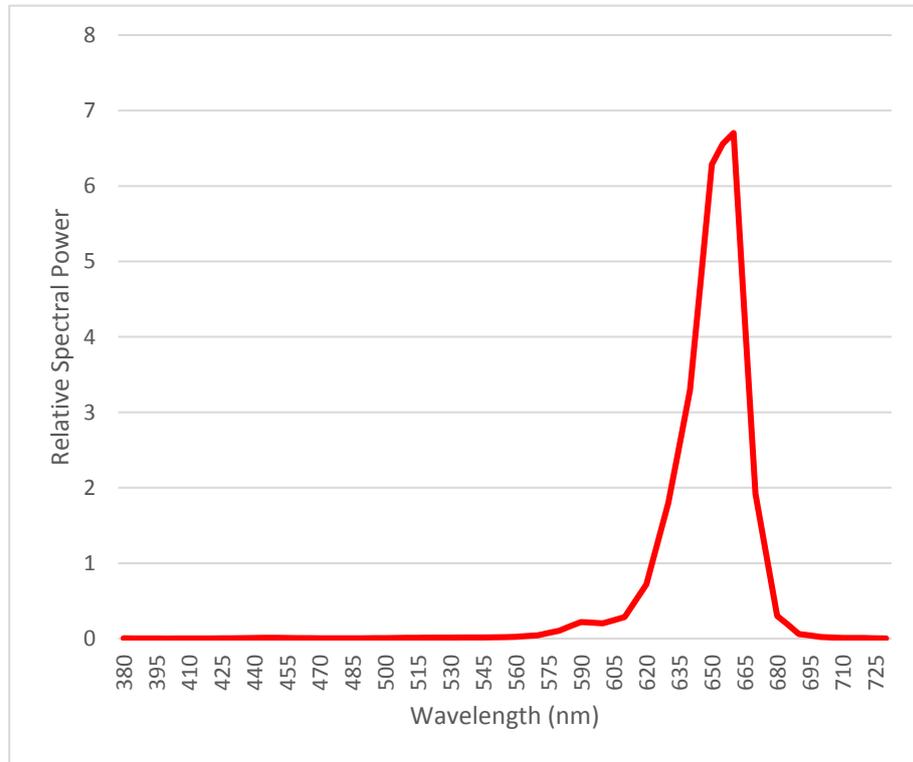


Figure 32: Spectral measurement of red environment

Table 9: Colorimeter readings of red environment

| | | |
|---------------------------|------------|------------|
| CIE | x = 0.6909 | y = 0.3011 |
| CCT | 1000 | |
| Lumi (CD/m ²) | 207.3 | |

Green Environment

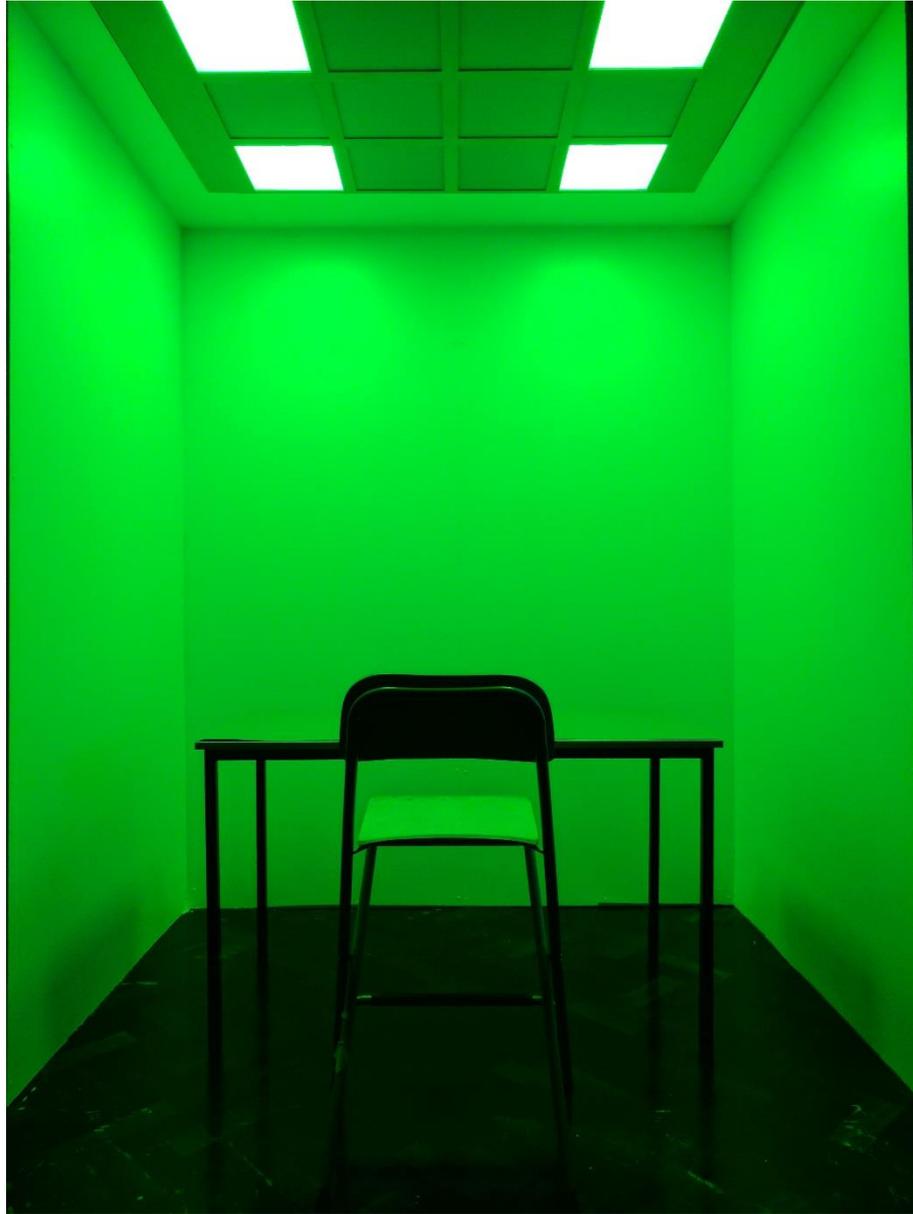


Figure 33: Green environment photograph.

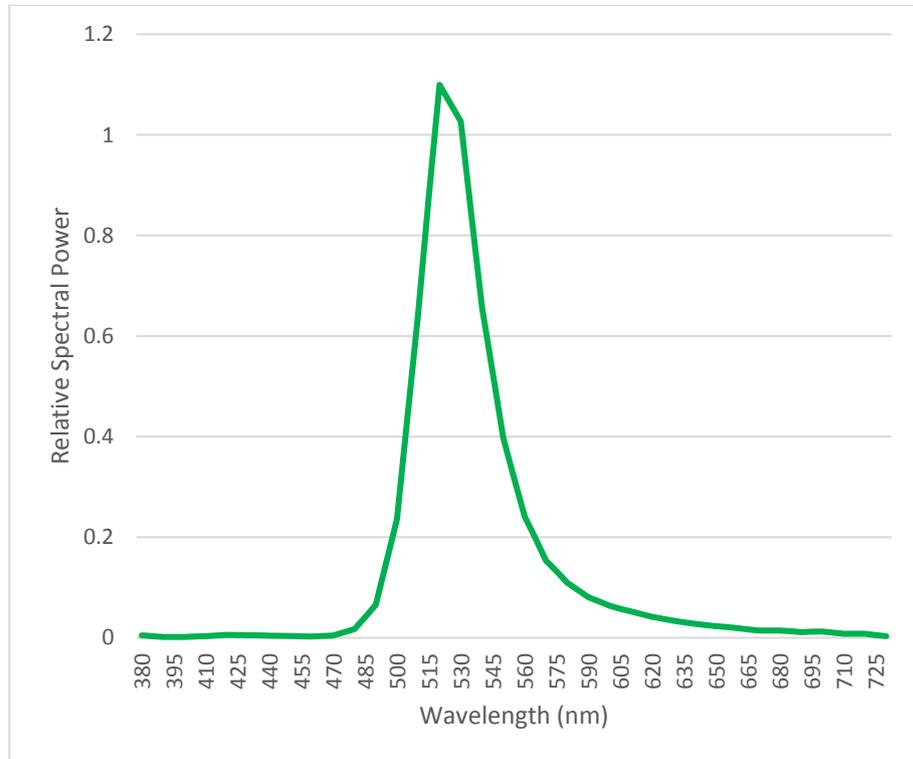


Figure 34: Spectral measurement of green environment.

Table 10: Colorimeter readings of green environment

| | | |
|---------------------------|------------|------------|
| CIE | x = 0.2351 | y = 0.6907 |
| CCT | 6920 | |
| Lumi (CD/m ²) | 247.6 | |

Blue Environment



Figure 35: Blue environment photograph.

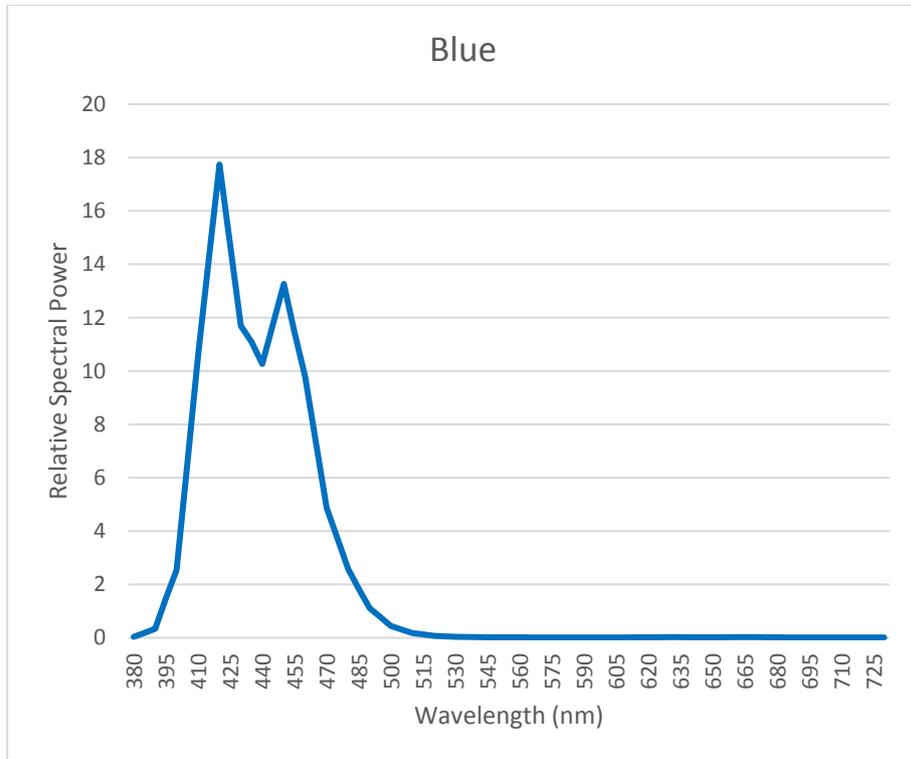


Figure 36: Spectral measurement of blue environment.

Table 11: Colorimeter readings of blue environment

| | | |
|---------------------------|------------|------------|
| CIE | x = 0.1560 | y = 0.0259 |
| CCT | 40000 | |
| Lumi (CD/m ²) | 197.3 | |

Yellow environment



Figure 37: Yellow environment photograph.

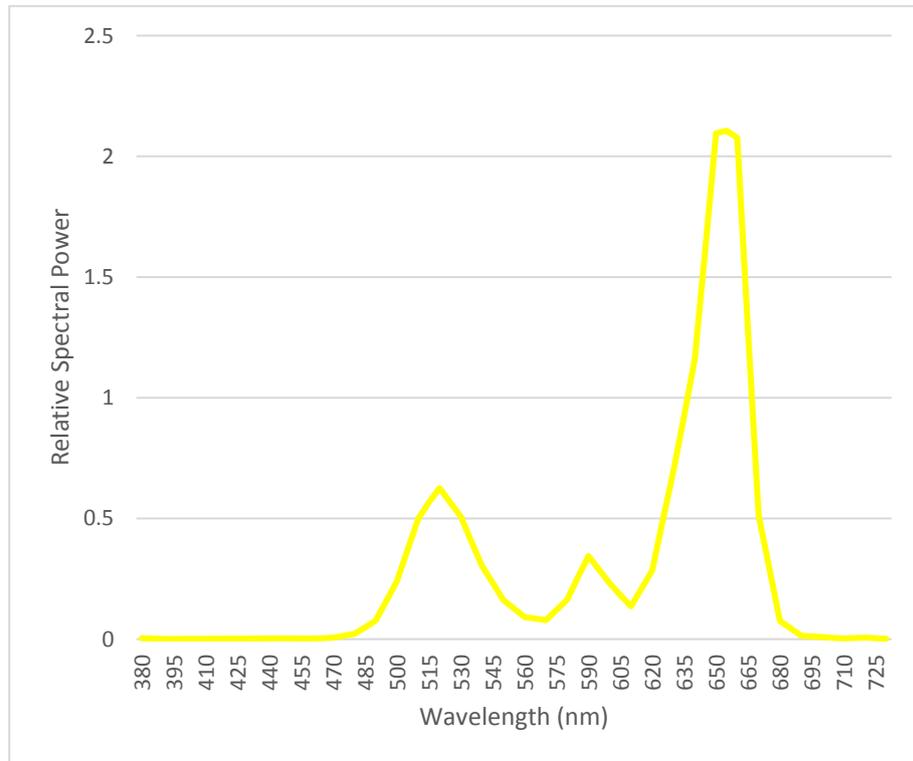


Figure 38: Spectral measurement of yellow environment.

Table 12: Colormeter readings of yellow environment.

| | | |
|---------------------------|----------|------------|
| CIE | x = 0.49 | y = 0.4663 |
| CCT | 2710 | |
| Lumi (CD/m ²) | 217.4 | |

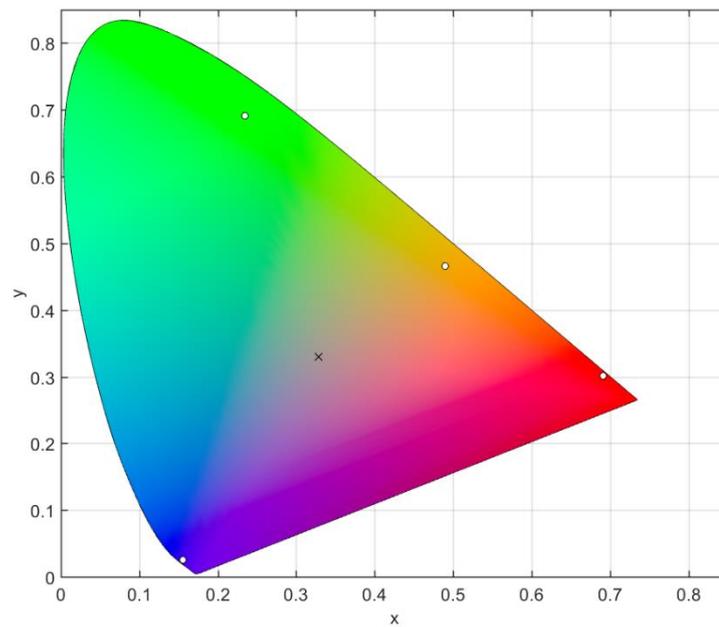


Figure 39: CIE Environment colour mapping.

3.6 Ethics

Each study abided by the British Psychological Sciences Code of Ethics and Conduct Guidelines (2009). Written consent was gained from every participant before the study. Each individual within the research was informed that they have the right to withdraw at any time without reason. A full debrief explaining the true experimental aims and purpose was given upon its completion. Participants' data and personal identities have been kept anonymous. The study underwent ethical approval through the Leeds University Ethical Committee for Design school wide research, passing the criteria for it to be conducted (please see appendices B, C & D for certificates).

3.7 Study 1: Personality Colour and Impulsivity

Hypothesis

H0a: State measures of impulsivity will be unaffected by changes in environment colour.

H0b: Trait measures of impulsivity will be unaffected by changes in environment colour.

H0c: Impulsivity scores will be unaffected by base impulsiveness.

H0d: Impulsivity scores will be unaffected by gender.

H1: Trait measures of impulsivity will be affected by changes in environment colour.

H2: Base impulsivity will affect impulsivity scores.

H3: Gender will affect impulsivity scores.

Procedure

Participant enter the experimental space under CIE Standard Illumination D65. They are instructed to read the information sheet (see appendix E) and fill out the consent form (see appendix F). The experimenter conducts the colour Ishihara deficiency test (Ishihara, 1917; In first trial only). Regardless of the result the test continues however colour deficient participants data will be marked not suitable for use. The LED cube illuminates the environment in a randomly selected condition. The control, D65 White or test colour red, green, blue or yellow. The experimenter then measure the CIE values of environment. The participant spends 3 minutes adaptation period in the colour environment before being asked to complete questionnaire 1, 2, 3 & 4 in a randomised order. The Environment CIE value is measured again checking for colour stability. Once all questionnaires have been completed the participant is informed that the study has ended, at which point the environment is illuminated in D65 for a short duration before the participant may exit.

Measures

Questionnaire 1: Barratt Impulsiveness Scale; BIS 11 (trait).

Questionnaire 2: State Impulsivity Scale; SIS (state).

Questionnaire 3: The Momentary Impulsivity Scale (state).

Questionnaire 4: Assessing Mood in Daily Life (state).

3.8 Study 2: Behaviour, colour and impulsivity

Hypothesis

H0e: Levels of Impulsive behaviour will be unaffected by environmental colour

H4: Impulsive behaviour levels will be affected by environmental colour.

Procedure

Participant enter the experimental space under CIE Standard Illumination D65. They are instructed to read the information sheet (see appendix E) and fill out the consent form (see appendix F). The experimenter conducts the colour Ishihara deficiency test (Ishihara, 1917; In first trial only). Regardless of the result the test continues however colour deficient participants data will be marked not suitable for use. The LED cube illuminates the environment in a randomly selected condition. The control, D65 White or test colour red, green, blue or yellow. The experimenter then measure the CIE values of environment. The participant spends 3 minutes adaptation period in the colour environment before being asked to complete computer based tasks 1 & 2. The Environment CIE value is measured again checking for colour stability. Once all questionnaires have been completed the participant is informed that the study

has ended, at which point the environment is illuminated in D65 for a short duration before the participant may exit.

Measures

Task 1: Cued go no-go task (Marczinski & Fillmore, 2003)

Task 2: The Balloon Analogue Risk Task (BART)

3.9 Study 3: Brain activity, colour and impulsivity

Hypothesis

H0f: Brainwave activity relating to impulsiveness will be unaffected by environmental colour.

H5: General brainwave activity relating to impulsiveness will be affected by environmental colour.

H6: Frontal brainwave activity relating to impulsiveness will be affected by environmental colour.

Procedure

Participant enter the experimental space under CIE Standard Illumination D65. They are instructed to read the information sheet (see appendix E) and fill out the consent form (see appendix F). The experimenter conducts the colour Ishihara deficiency test (Ishihara, 1917; In first trial only). Regardless of the result the test continues however colour deficient participants data will be marked not suitable for use. The EEG Device is placed on the participant and tested for low impedance. The LED cube illuminates the environment in a randomly selected condition. The control, D65 White or test colour red, green, blue or yellow. The experimenter then measure the CIE values of environment. The participant spends 3 minutes adaptation period in the colour environment before the EEG recording begins. They are then asked to complete computer based cued Go/ No go task. The Environment CIE value is measured again. Once all questionnaires have been completed the participant is informed that the study has ended, at which point the EEG recording is ended and the environment is illuminated in D65. The EEG device is removed before the participant may exit.

Measures

Task 1: Cued go no-go task (Marczinski & Fillmore, 2003)

EEG: 9 channels over period of study.

4. Results

The same participants recruited through opportunity sampling amongst Leeds University students were used across each study, therefore repeated measures ANOVA's could be used to identify any within-subject main effects. If a significant ($p = < 0.05$) or marginally significant effect ($p = < 0.10$) was found Bonferroni post hoc analysis was used to understand the directional nature of the effect. Univariate ANOVAS were used for between-subject factors (gender and base impulsivity level). There were no colour deficient subjects (screened using the Ishihara Colour Vision Test).

4.1 Study 1: Personality Colour and Impulsivity

Table 13: Participant descriptives

| Gender | | Base Impulsiveness | |
|--------|--------|--------------------|------|
| Male | Female | Low | High |
| 13 | 12 | 16 | 9 |

Questionnaire 1: Barratt Impulsiveness Scale; BIS 11 (trait)

Table 14: Q1 Barratt Impulsiveness Scale Score and Colour

| Colour | Mean | Std. Error | 95% Confidence Interval | |
|--------|-------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 69.37 | 1.50 | 66.26 | 72.48 |
| Red | 70.25 | 1.24 | 67.67 | 72.83 |
| Blue | 67.26 | 1.13 | 64.91 | 69.60 |
| Green | 67.86 | 1.13 | 65.52 | 70.21 |
| Yellow | 68.51 | 1.15 | 66.11 | 70.90 |

A repeated measures ANOVA was conducted which found no main effect of colour $F(1.9, 39) = 1.15, p = .323$ however there was a main effect of between subject factors of base impulsiveness and impulsivity score $F(1, 21) = 24.21, p = <.001$ and an interaction between Gender and base impulsiveness $F(1, 21) = 4.75, p = .041$.

Table 15: Q1 score and base impulsiveness descriptives.

| Baselmp | Mean | Std. Error | 95% Confidence Interval | |
|---------|-------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| Low | 65.01 | .89 | 63.17 | 66.86 |
| High | 72.29 | 1.18 | 69.83 | 74.74 |

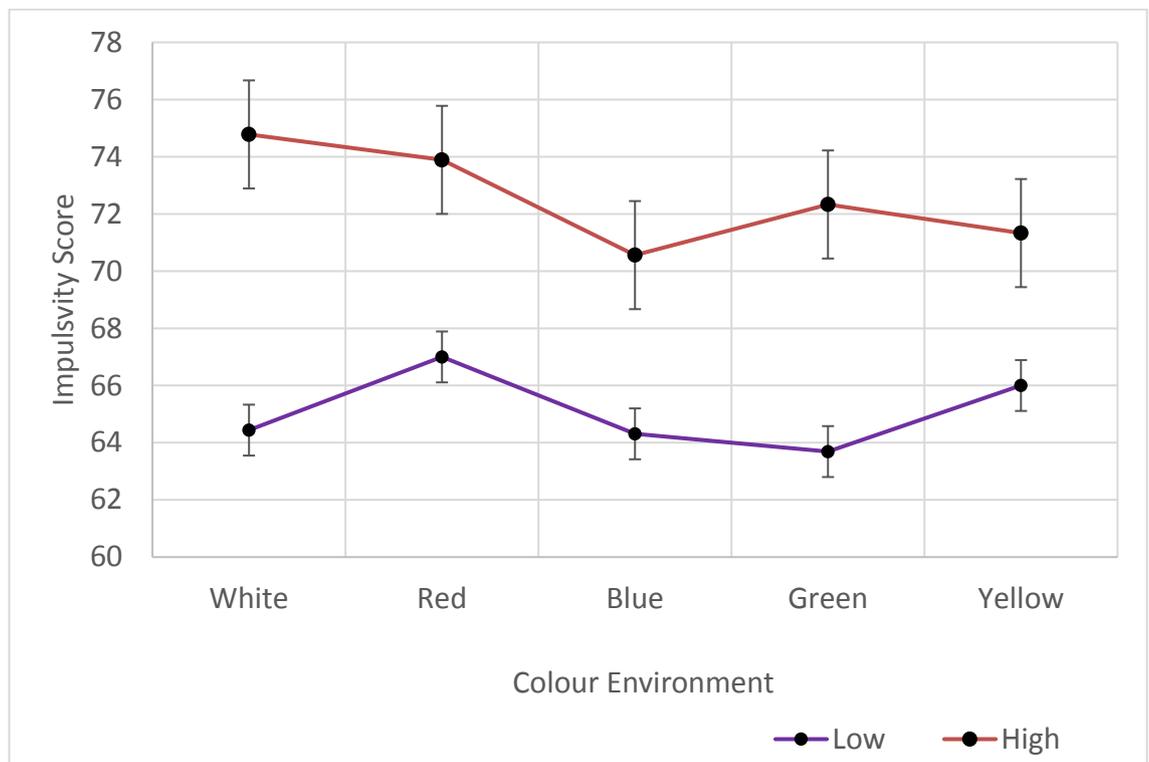


Figure 40: Mean comparison of base impulsiveness and Q1 impulsivity score across colours.

Table 16: Q1 score Gender and Base Impulsivity descriptives.

| Base Imp | Gender | Mean | Std. Error | 95% Confidence Interval | |
|----------|--------|-------|------------|-------------------------|-------------|
| | | | | Lower Bound | Upper Bound |
| Low | Male | 65.60 | 1.17 | 63.16 | 68.04 |
| | Female | 64.43 | 1.33 | 61.66 | 67.20 |
| High | Male | 69.65 | 1.76 | 65.99 | 73.31 |
| | Female | 74.92 | 1.58 | 71.64 | 78.20 |

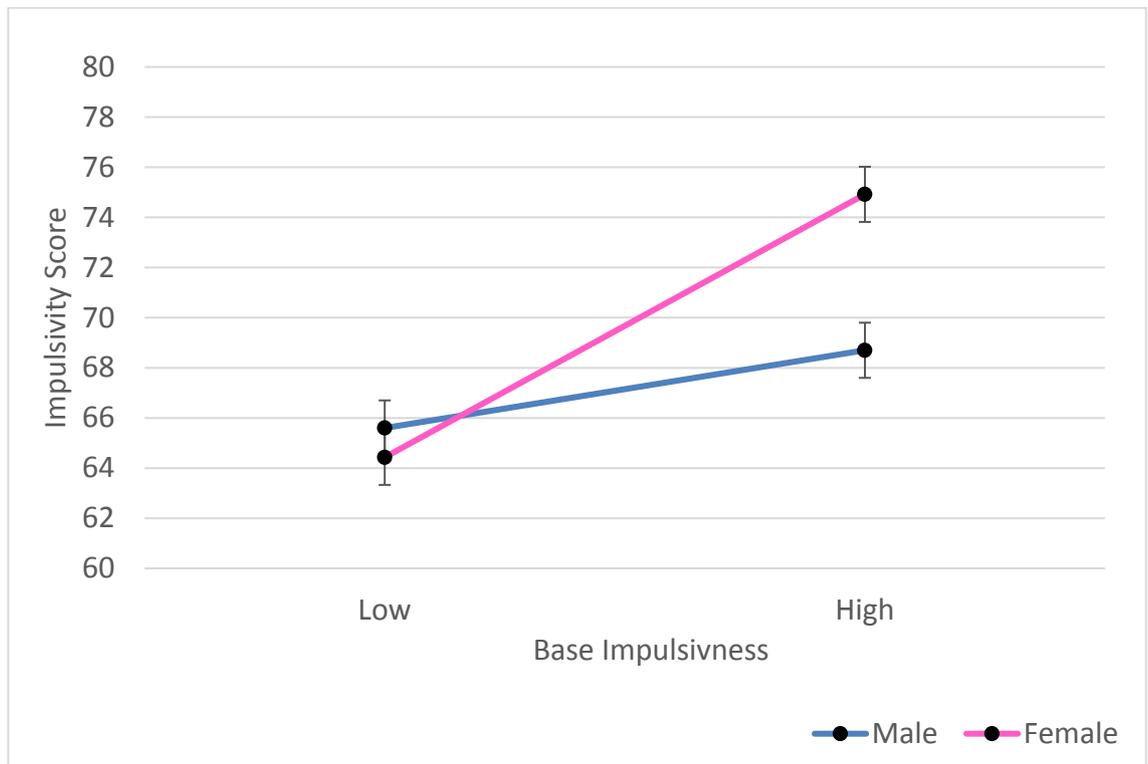


Figure 41: Interaction between Gender and Base impulsiveness Q1 impulsivity scores.

Questionnaire 2: State Impulsivity Scale; SIS (state)

Table 17: Q2 SIS Score and Colour descriptives.

| Colour | Mean | Std. Error | 95% Confidence Interval | |
|--------|-------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 41.52 | 1.97 | 37.46 | 45.58 |
| Red | 42.56 | 1.85 | 38.74 | 46.38 |
| Blue | 40.80 | 1.90 | 36.89 | 44.71 |
| Green | 41.76 | 1.85 | 37.95 | 45.57 |
| Yellow | 40.92 | 1.76 | 37.29 | 44.55 |

A repeated measures ANOVA was conducted which found no main effect of colour $F(1.5, 32) = .082, p = .877$ but a significant main effect of base impulsiveness $F(1, 21) = 4.94, p = .037$.

Table 18: Q2 score and base impulsiveness descriptives.

| Base Imp | Mean | Std. Error | 95% Confidence Interval | |
|----------|-------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| Low | 39.11 | 1.68 | 35.64 | 42.58 |
| High | 45.78 | 2.24 | 41.15 | 50.41 |

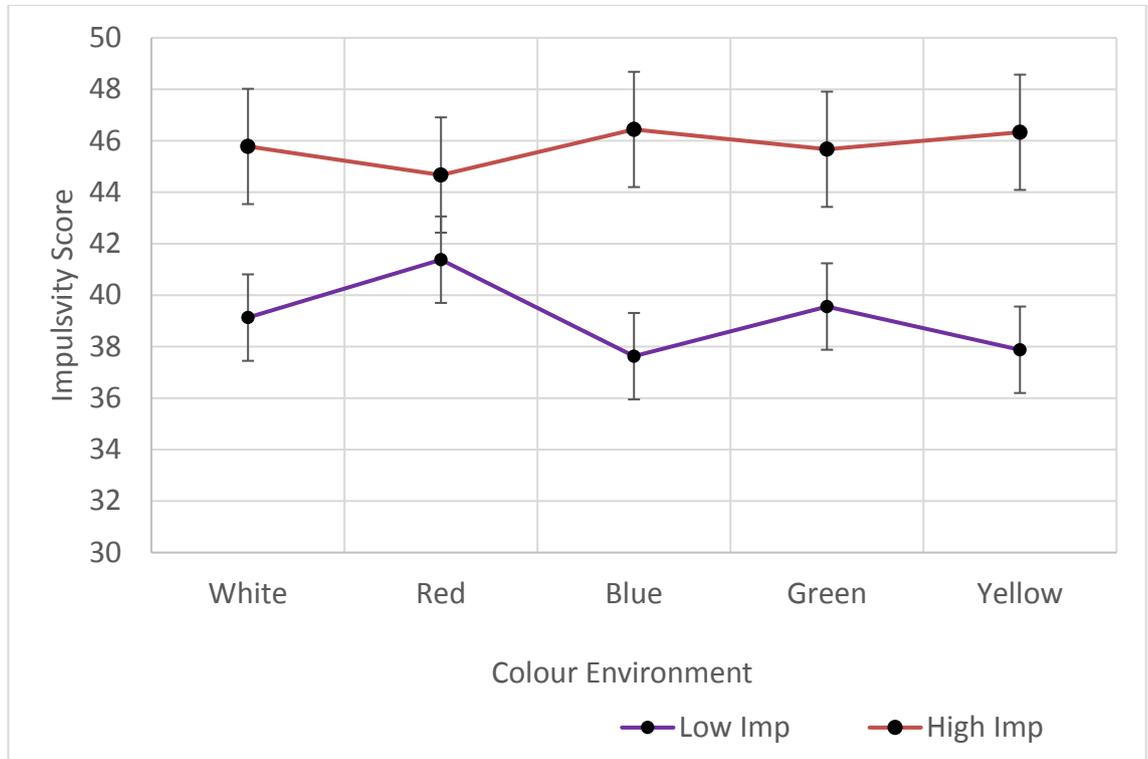


Figure 42: Mean comparison of base impulsiveness and Q2 impulsivity score.

Questionnaire 3: The Momentary Impulsivity Scale (state)

Table 19: Q3 Momentary Impulsivity Scale Score and Colour descriptives.

| Colour | Mean | Std. Error | 95% Confidence Interval | |
|--------|------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 9.85 | .28 | 9.27 | 10.44 |
| Red | 9.99 | .46 | 9.03 | 10.94 |
| Blue | 9.77 | .44 | 8.85 | 10.69 |
| Green | 9.76 | .47 | 8.79 | 10.73 |
| Yellow | 9.76 | .43 | 8.86 | 10.66 |

A repeated measures ANOVA was conducted which found no main effect of colour $F(3.01, 64) = 6.97, p = .903$ but two between subject factor effects of base impulsiveness $F(1, 21) = 6.97, p = .015$ and Gender $F(1, 21) = 7.48, p = .012$.

Table 20: Q3 score and base impulsiveness descriptives.

| BasImp | Mean | Std. Error | 95% Confidence Interval | |
|--------|-------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| Low | 8.84 | .45 | 7.91 | 9.77 |
| High | 10.81 | .60 | 9.57 | 12.05 |

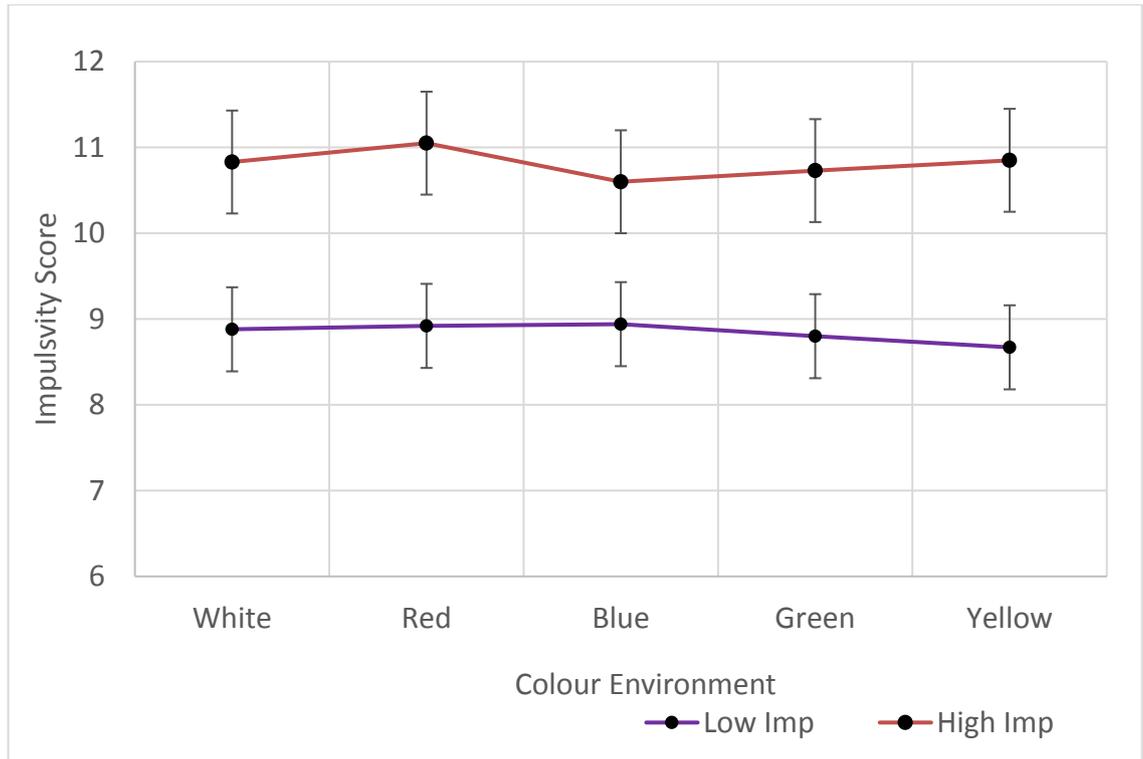


Figure 43: Mean comparison of base impulsiveness and Q3 impulsivity score.

Table 21: Q3 score and gender descriptives.

| Gender | Mean | Std. Error | 95% Confidence Interval | |
|--------|-------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| Male | 8.81 | .53 | 7.70 | 9.92 |
| Female | 10.85 | .52 | 9.76 | 11.93 |

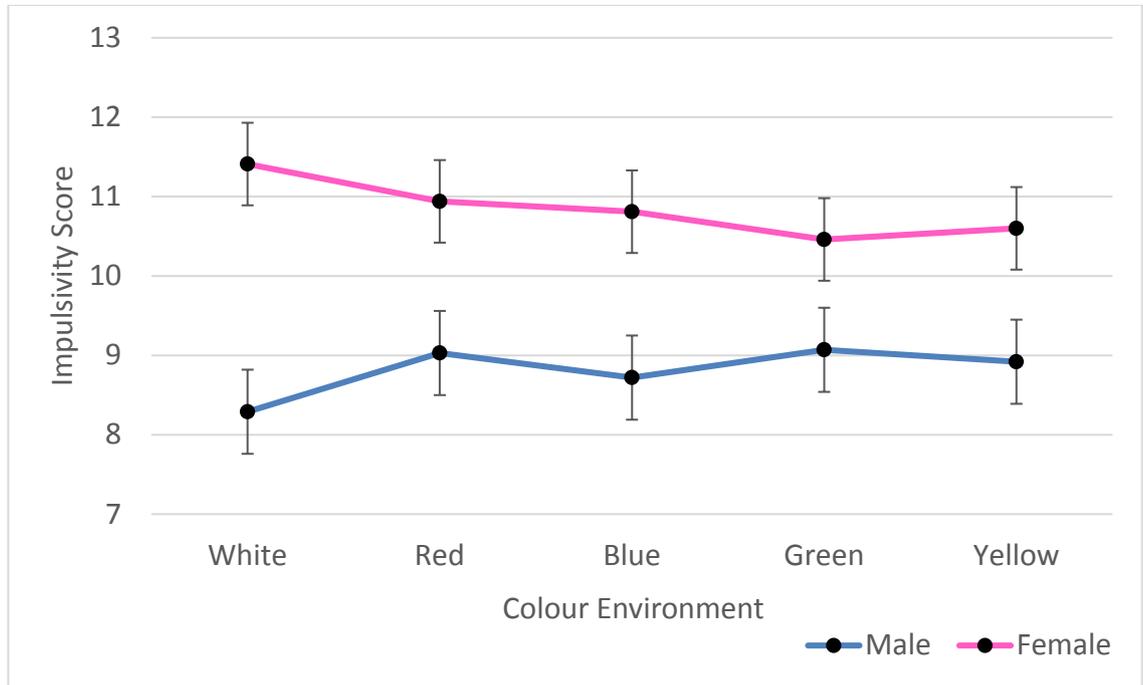


Figure 44: Mean comparison of Q3 score, gender and colour.

Questionnaire 4: Assessing Mood in Daily Life (state).

Due to the nature of the Assessing Mood in Daily Life questionnaire the data set contained negative scores, therefore results went through a process to normalise them. This involved finding the largest positive number and the smallest most negative number in the array, then adding the absolute value of the smallest most negative number to every value in the array. Dividing each result by the difference between the largest and the smallest number then multiplying that number by 100.

Table 22: Q4 Assessing Mood in Daily Life Score and Colour descriptives.

| Colour Env | Mean | Std. Error | 95% Confidence Interval | |
|------------|-------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 54.56 | 3.88 | 46.56 | 62.56 |
| Red | 37.76 | 4.15 | 29.19 | 46.33 |
| Blue | 56.48 | 3.85 | 48.53 | 64.43 |
| Green | 55.04 | 3.37 | 48.08 | 62.00 |
| Yellow | 49.92 | 4.21 | 41.23 | 58.61 |

A repeated measures ANOVA was conducted which found a main effect of colour on impulsiveness score $F(4, 96) = 7.14, p < .001$.

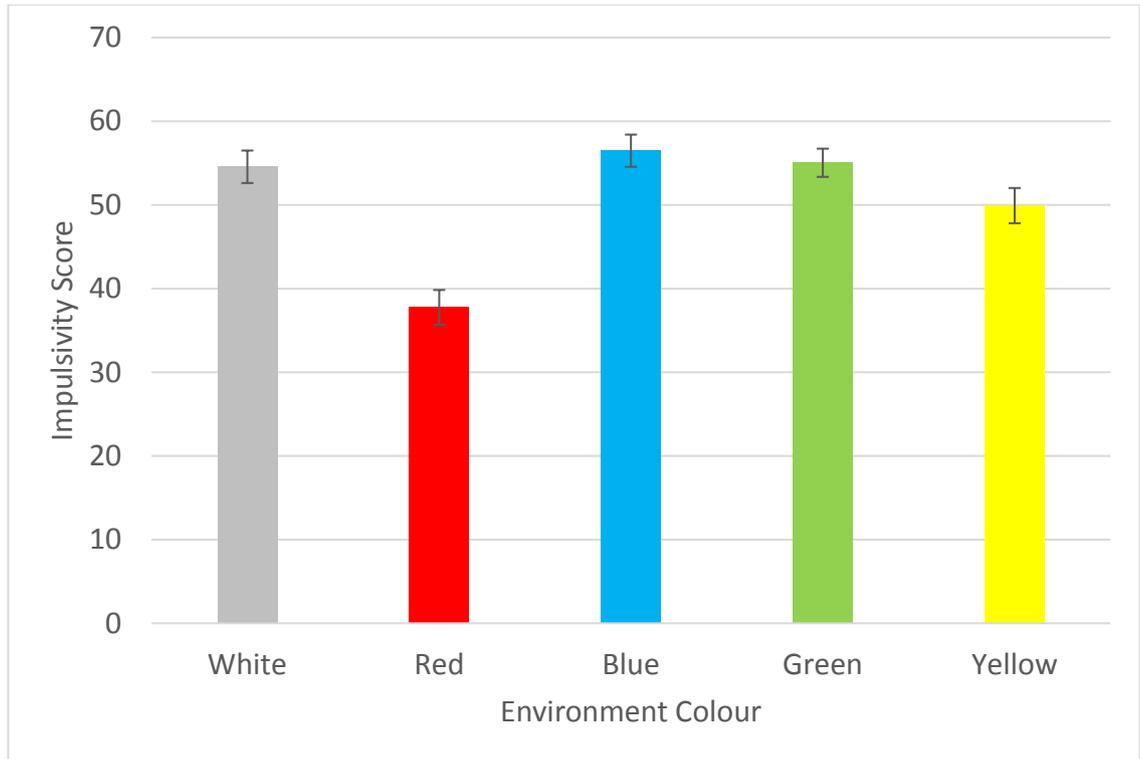


Figure 45: Mean comparison of Q4 impulsivity score and colour (lower score indicates higher impulsiveness).

A Bonferroni post-hoc test was used to find the directional nature of the main effect of colour (see appendix G). Red ($M = 37.7600, SD = 20.75508$) was significantly lower in score than White ($M = 54.56, SD = 19.39$) ($p = .001$), Green ($M = 55.0400, SD = 16.86$) ($p = .001$) & Blue ($M = 56.4800, SD = 19.26$) ($p = .008$).

4.2 Study 2: Behaviour, colour and impulsivity

Go / No- Go Task.

Thirty five participants conducted this Go/ No-Go Task reaction time and Error rate are the measured outputs of this task. There was a marginally significant effect of coloured environment on error percentage $F(4, 136) = 2.11, p = .082$.

Table 23: Error rate % and colour descriptives.

| Colour Env | Mean | Std. Error | 95% Confidence Interval | |
|------------|------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | .91 | .31 | .29 | 1.54 |
| Red | .63 | .16 | .31 | .95 |
| Blue | .46 | .14 | .18 | .74 |
| Green | .94 | .23 | .48 | 1.41 |
| Yellow | .26 | .13 | 0 | .51 |

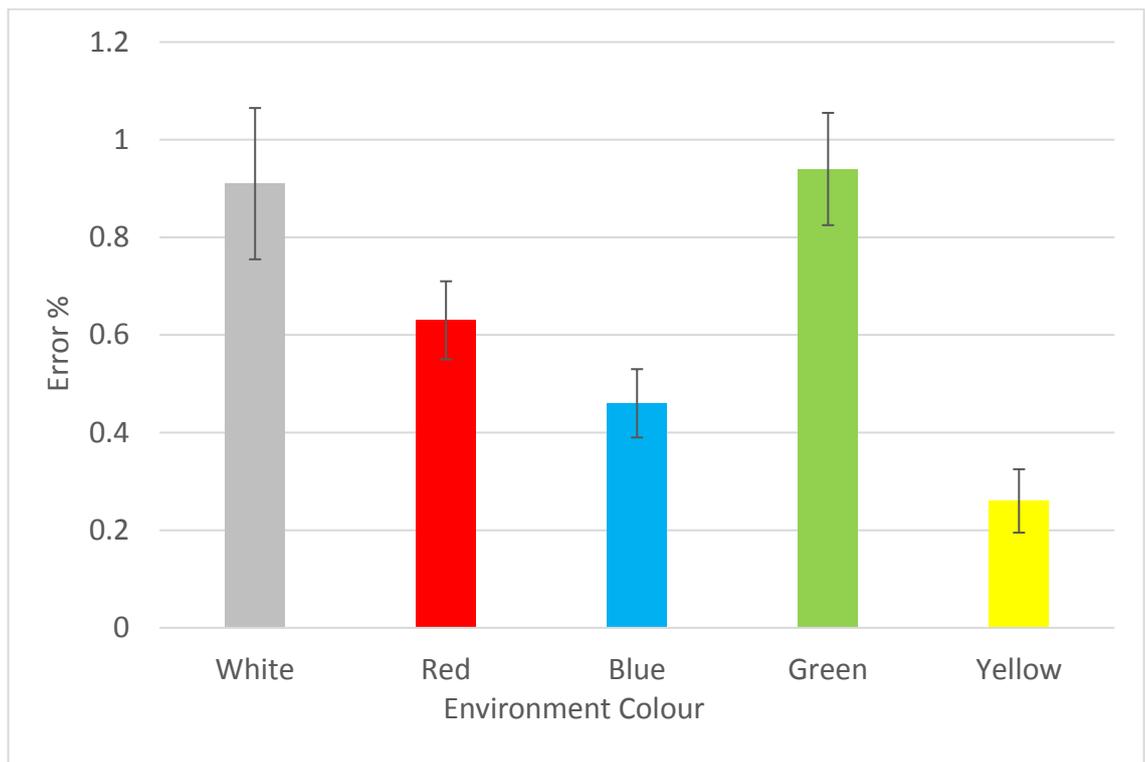


Figure 46: Go / No-Go Error rate % mean difference between colours.

A Bonferroni post-hoc test was used to find the directional nature of the main effect however this test came back insignificant.

There was a significant main effect of colour and reaction time $F(4, 136) = 17.35, p = <.001$.

Table 24: Reaction time (ms) and colour descriptives

| Colour Env | Mean | Std. Error | 95% Confidence Interval | |
|------------|--------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 340.45 | 7.12 | 325.98 | 354.93 |
| Red | 361.50 | 6.82 | 347.65 | 375.34 |
| Blue | 318.30 | 4.69 | 308.77 | 327.82 |
| Green | 325.10 | 5.70 | 313.46 | 336.64 |
| Yellow | 340.57 | 5.16 | 330.07 | 351.06 |

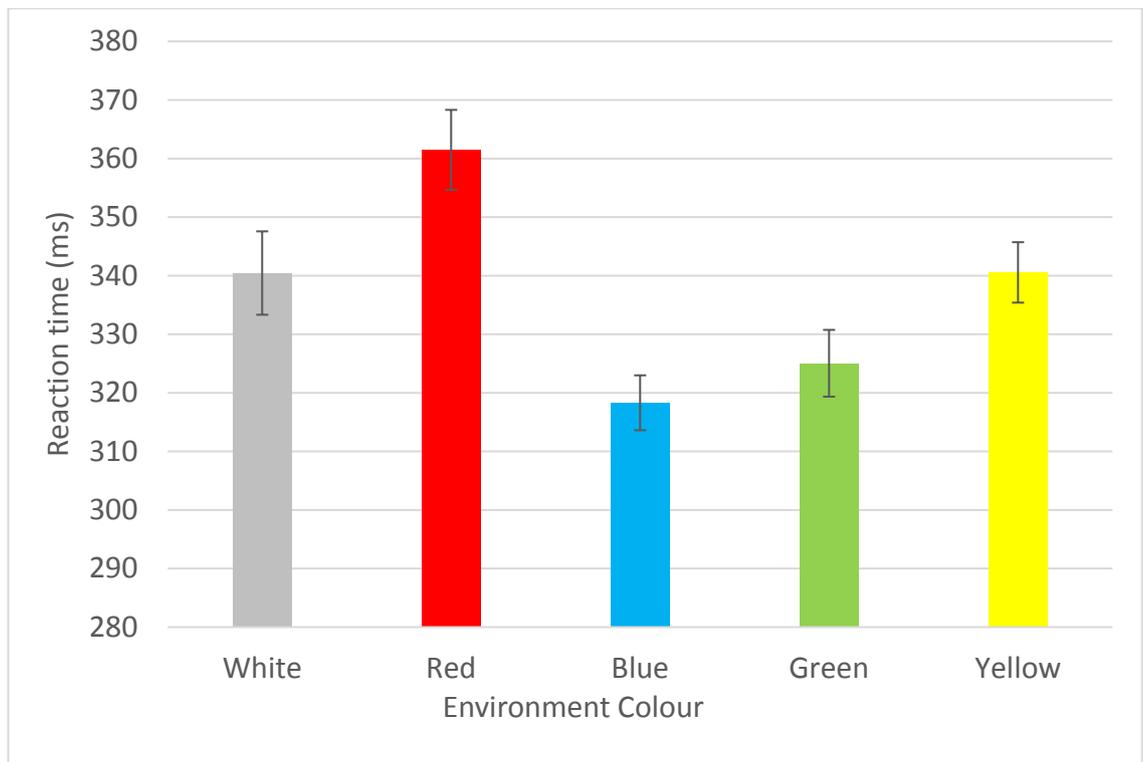


Figure 47: Mean reaction time (ms) and colour comparison.

A Bonferroni post-hoc test was used to find the directional nature of the main effect of colour (see appendix G. Reaction times in the blue condition Blue (M = 318.295 SD = .81684) were faster than white (M = 340.451 SD=1.82098 p = .013), red (M = 361.495 SD = .94202 p = <.001) and yellow (M = 340.565 SD = .74134 p = <.001). Reaction times were slower in the red condition (M = 361.495 SD = .94202) than blue (M = 318.295 SD = .81684 p = <.001) green (M = 325.050 SD = 1.34914 p = <.001) and yellow (M = 340.565 SD = .74134 .004). While reaction times under green light (M = 325.050 SD = 1.34914) were faster than in yellow (M = 340.565 SD = .74134 p = .005).

BART Task

Average pump count $F(4, 136) = .484, p = .747$, number of balloon bursts $F(4, 136) = 2.8, p = .029$, time before first pump $F(2.43, 91.7) = .258, p = .814$, time between pumps $F(2.79, 94.84) = .481, p = .749$, total number of pumps $F(4, 136) = .612, p = .655$ and time to complete the tasks $F(1.03, 35.05) = .927, p = .345$ are all measured during this task. Out of these measures a significant main effect of colour on balloon bursts was found using a repeated measure ANOVA $F(4, 136) = 2.8, p = .029$.

Table 25: Balloon bursts and colour descriptives.

| Colour Env | Mean | Std. Error | 95% Confidence Interval | |
|------------|------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 2.74 | .19 | 2.37 | 3.12 |
| Red | 3.43 | .43 | 2.56 | 4.30 |
| Blue | 4.0 | .41 | 3.16 | 4.84 |
| Green | 3.26 | .38 | 2.49 | 4.03 |
| Yellow | 3.63 | .39 | 2.83 | 4.42 |

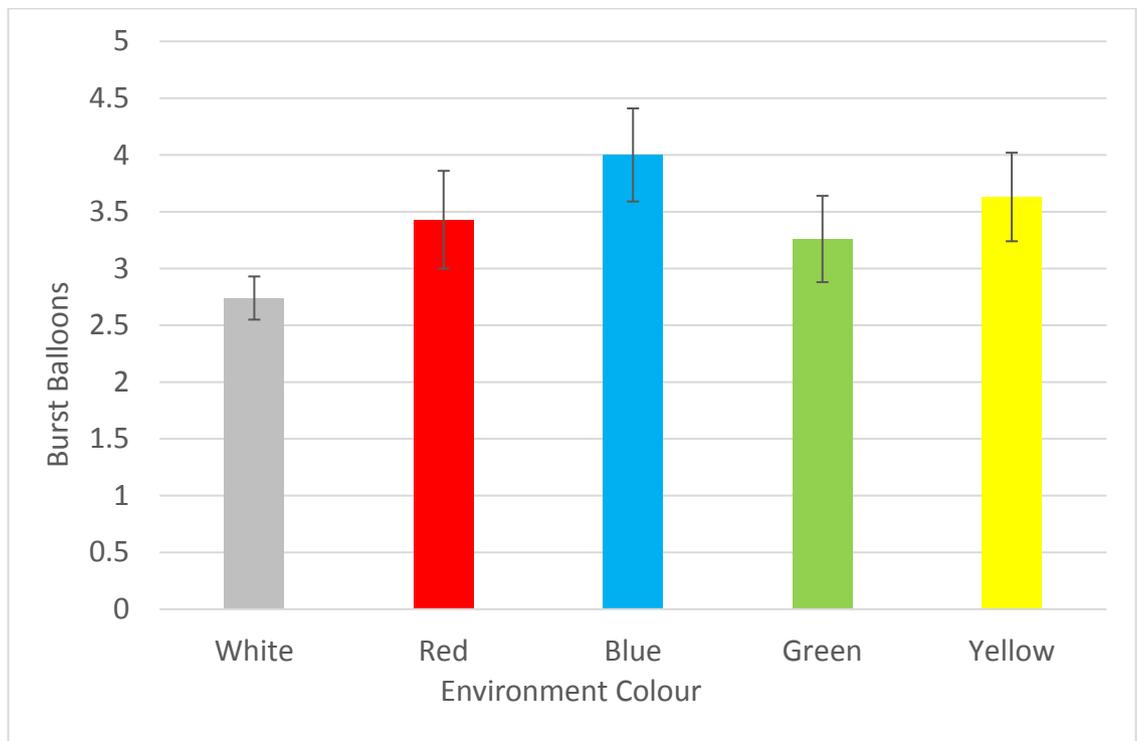


Figure 48: Balloon burst and colour comparison.

A Bonferroni post-hoc test was used to find the directional nature of the main effect of colour on balloon bursts (see appendix G). It was found that there were more bursts in blue ($M = 4.00$ $SD = 2.45$) than white ($M = 2.74$ $SD = 1.09$ $p = .018$).

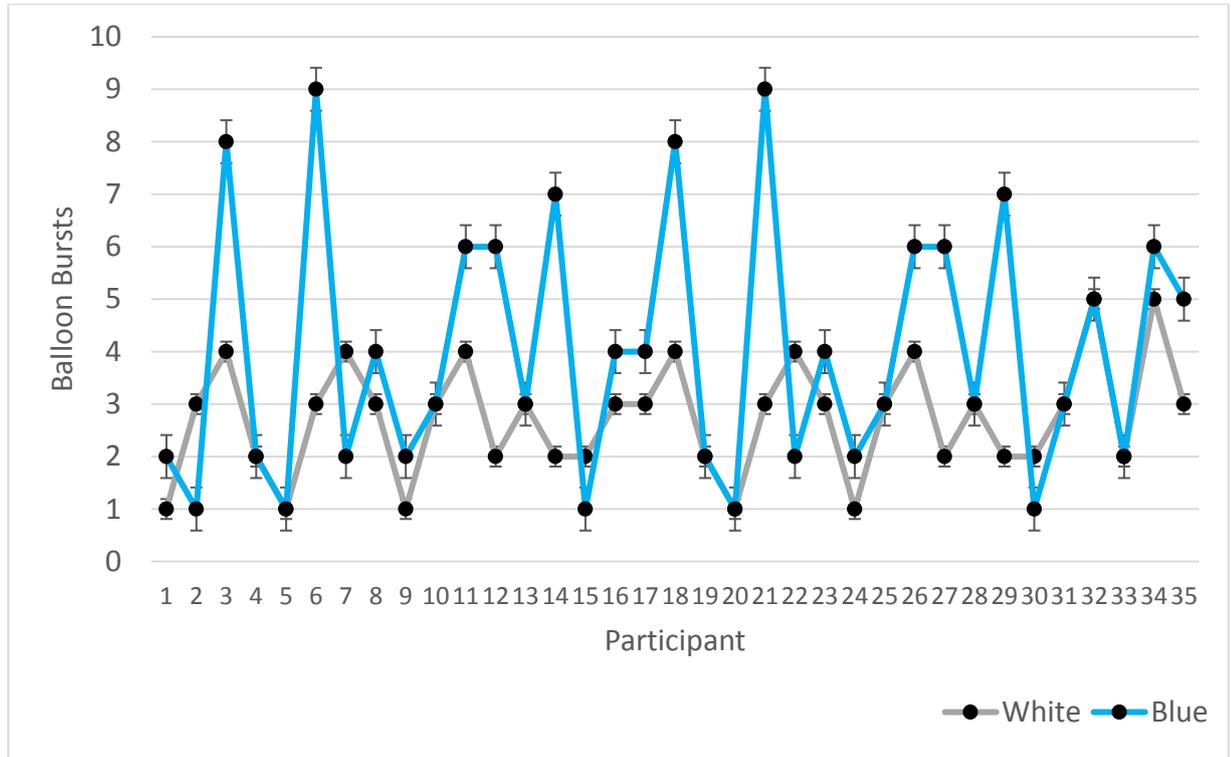


Figure 49: Colour and balloon bursts between white and blue.

4.3 Study 3: Brain activity, colour and impulsivity

The brain imaging component of this research is exploratory, there are yet to be any accurately defined EEG parameters for impulsivity. However using a small number of participants ($n = 5$) will be useful in finding any associations between coloured environment, brain wave activity and impulsivity, without spending too many resources and having limited time within a PhD period. Thus this should be seen as a hypothesis-generating study with a larger confirmatory study to be carried out as part of future work. Participants completed a Go/ No go task while fitted with an EEG. Total Theta (4-8 Hz), Alpha (8-14 Hz) and Beta (14-40 Hz) waves were measures and also Theta, Alpha and Beta waves in the frontal regions F3, FZ and F3.

Theta (4-8 Hz) total brain activity

Table 26: Total Theta activity and colour descriptives.

| Colour Env | Mean | Std. Error | 95% Confidence Interval | |
|------------|------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 3.54 | .13 | 3.18 | 3.89 |
| Red | 3.31 | .08 | 3.10 | 3.52 |
| Blue | 3.65 | .09 | 3.39 | 3.91 |
| Green | 3.44 | .09 | 3.18 | 3.70 |
| Yellow | 3.64 | .14 | 3.25 | 4.02 |

A repeated measures ANOVA was conducted which found a main effect of colour on total theta activity $F(4, 16) = 5.63, p = .005$.

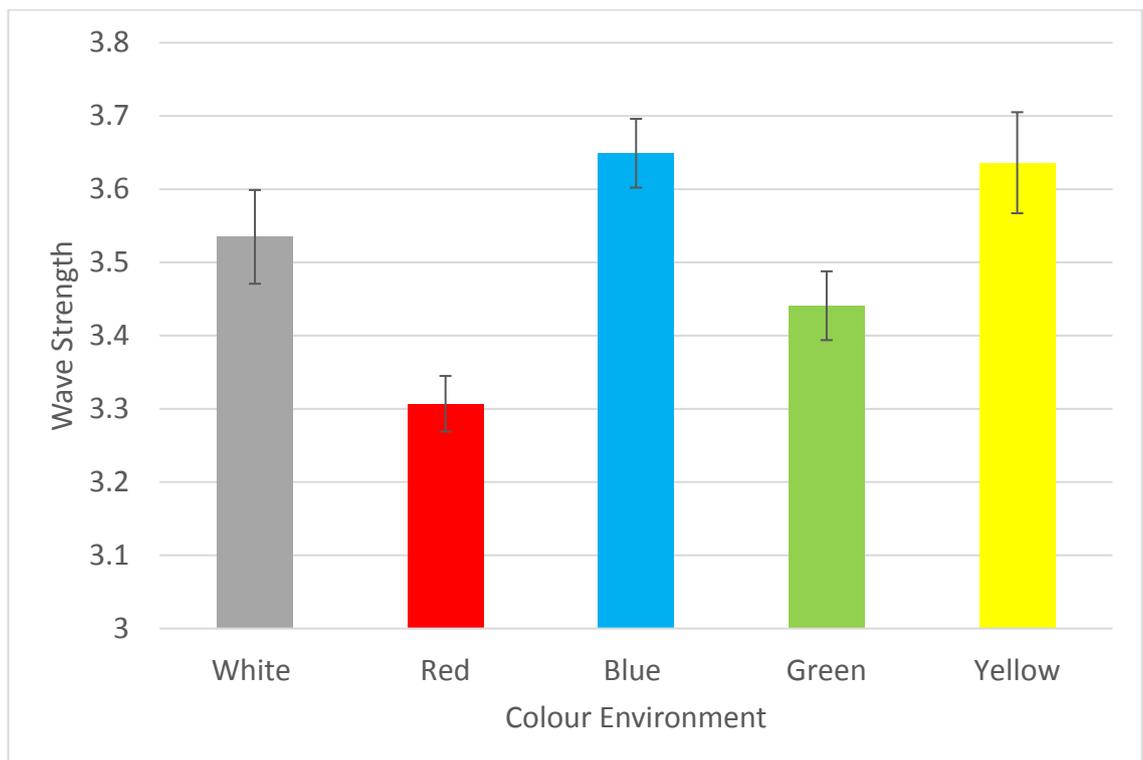


Figure 50: Total Theta wave and colour comparison.

A Bonferroni post-hoc test was used to find the directional nature of the main effect however this test came back insignificant.

Alpha (8-14 Hz) total brain activity

Table 27: Total Alpha activity and colour descriptives.

| Colour Env | Mean | Std. Error | 95% Confidence Interval | |
|------------|------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 2.99 | .04 | 2.87 | 3.11 |
| Red | 2.74 | .03 | 2.66 | 2.82 |
| Blue | 3.08 | .05 | 2.95 | 3.22 |
| Green | 2.84 | .03 | 2.75 | 2.93 |
| Yellow | 3.07 | .07 | 2.88 | 3.27 |

A repeated measures ANOVA was conducted which found a main effect of colour on total Alpha activity $F(4, 16) = 24.33, p = <.001$.

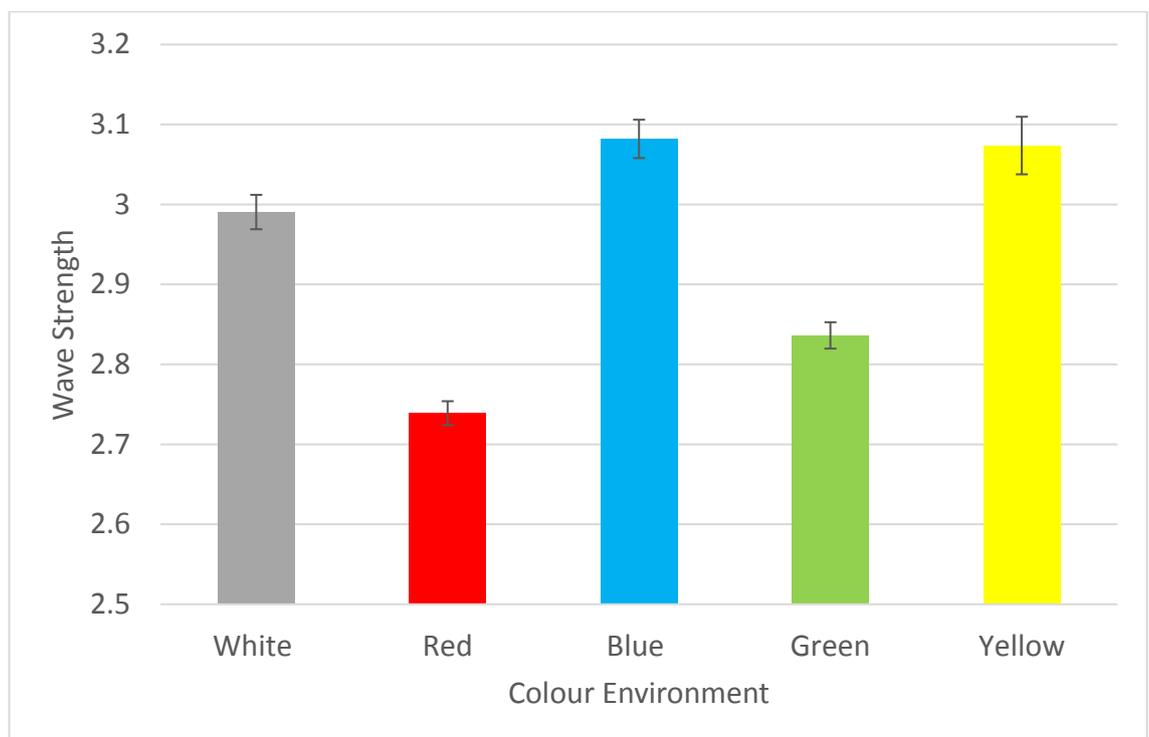


Figure 51: Total Alpha wave and colour comparison.

A Bonferroni post-hoc test was used to find the directional nature of the main effect (see appendix G). In the red condition (M = 2.74 SD = .068) activity was significantly lower than white (M = 2.99 SD = .097; $p = .025$) blue (M = 3.08 SD = .11; $p = .032$) and Yellow (M = 3.07 SD = .16; $p = .031$).

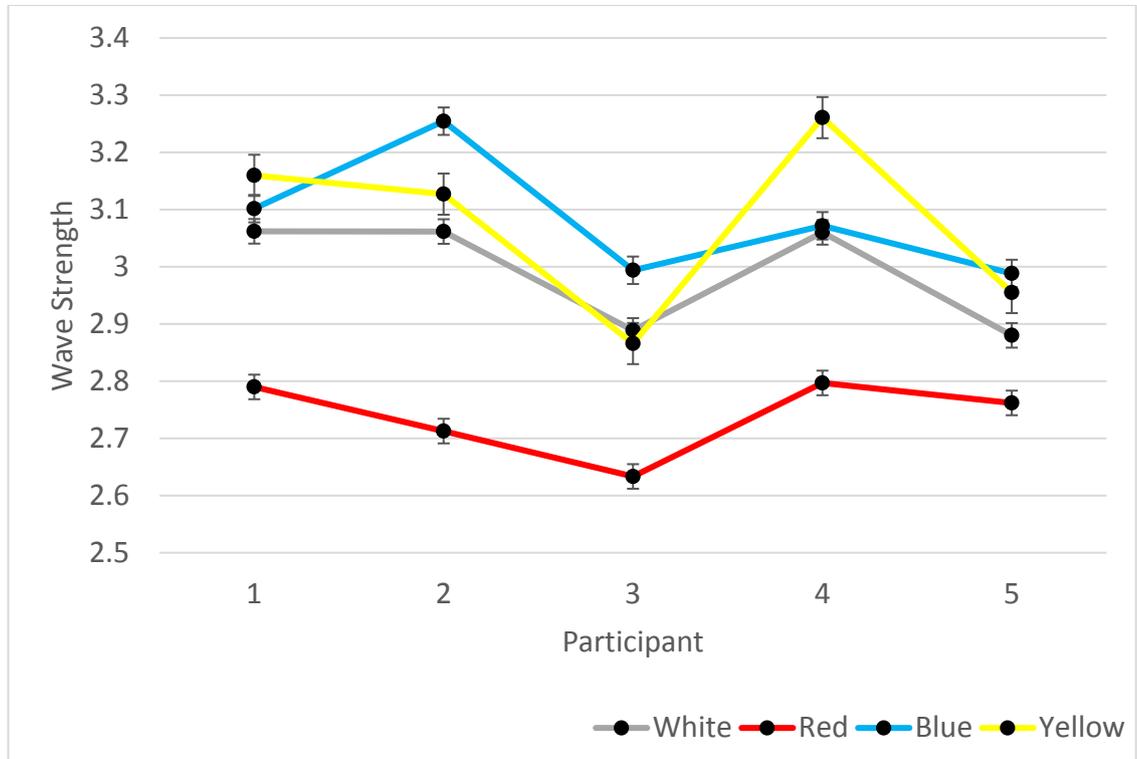


Figure 52: Comparison of white, red, blue and yellow total Alpha waves across participants.

Beta (14-40 Hz) total brain activity

Table 28: Total Beta activity and colour descriptives.

| Colour Env | Mean | Std. Error | 95% Confidence Interval | |
|------------|------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 2.51 | .04 | 2.41 | 2.61 |
| Red | 2.40 | .03 | 2.31 | 2.49 |
| Blue | 2.57 | .05 | 2.44 | 2.70 |
| Green | 2.47 | .04 | 2.36 | 2.59 |
| Yellow | 2.59 | .05 | 2.44 | 2.74 |

A repeated measures ANOVA was conducted which found a main effect of colour on total Beta activity $F(4, 16) = 14.28, p = <.001$.

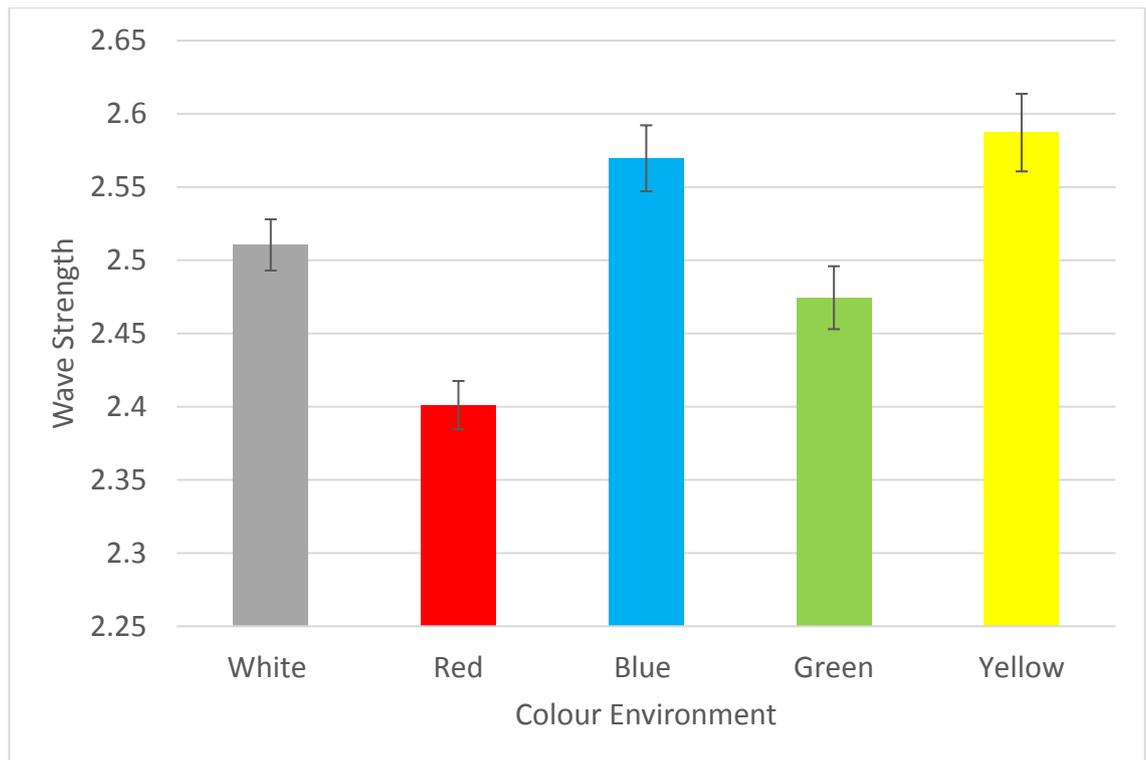


Figure 53: Total Alpha wave and colour comparison.

A Bonferroni post-hoc test was used to find the directional nature of the main effect (see appendix G). In the red condition (M = 2.40 SD = .078) activity was significantly lower than white (M = 2.51 SD = .078; $p = .010$) and blue (M = 2.57 SD = .10; $p = .033$).

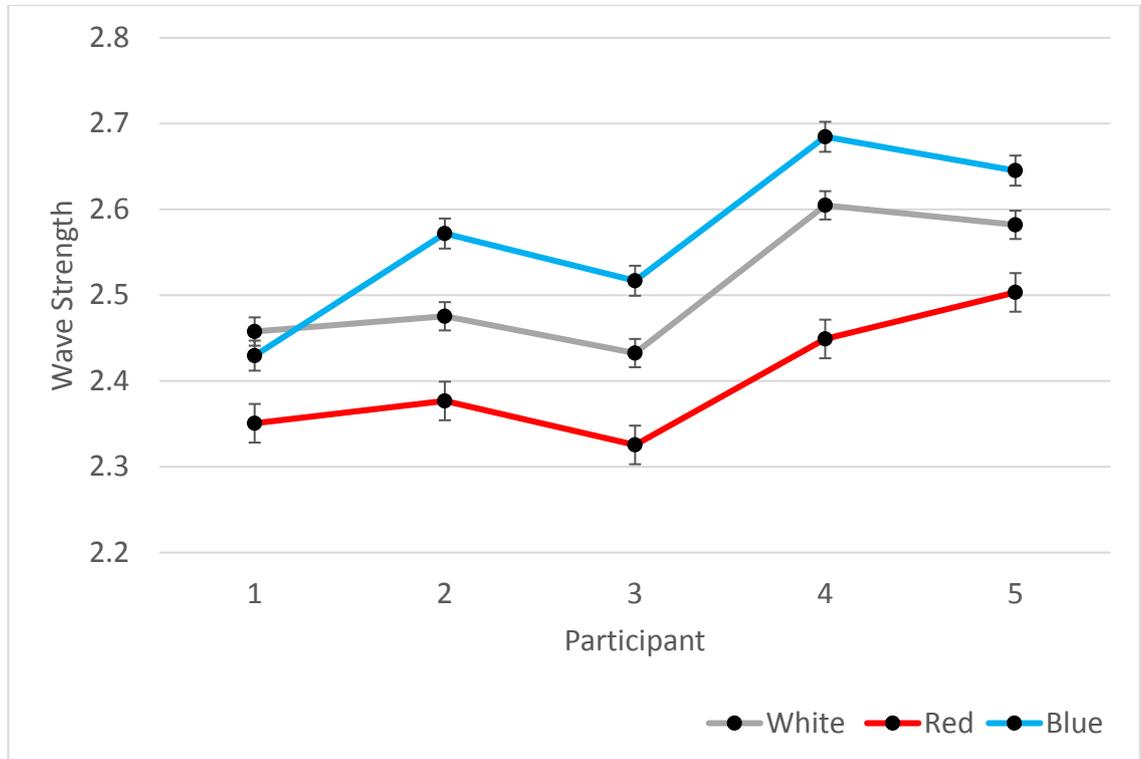


Figure 54: Comparison of white, red and blue total Beta waves across participants.

Frontal (F3, FZ and F3) Theta waves.

Table 29: Frontal Theta activity and colour descriptives.

| Colour Env | Mean | Std. Error | 95% Confidence Interval | |
|------------|------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 3.78 | .16 | 3.34 | 4.23 |
| Red | 3.48 | .10 | 3.21 | 3.75 |
| Blue | 3.92 | .12 | 3.59 | 4.25 |
| Green | 3.65 | .11 | 3.33 | 3.97 |
| Yellow | 3.90 | .17 | 3.43 | 4.36 |

A repeated measures ANOVA was conducted which found a main effect of colour on F3, FZ and F3 theta activity $F(4, 16) = 6.04, p = .004$.

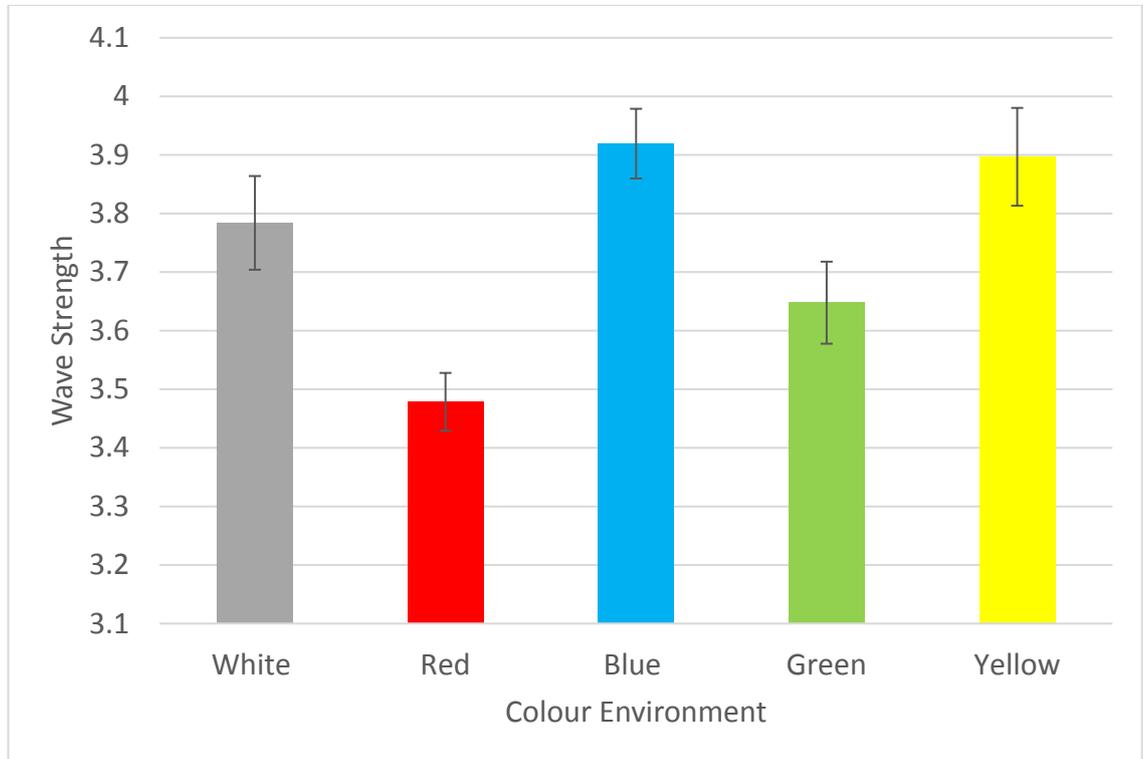


Figure 55: Frontal Theta wave and colour comparison

A Bonferroni post-hoc test was used to find the directional nature of the main effect however there were no significant between colours.

Frontal (F3, FZ and F3) Beta waves.

Table 30: Frontal Beta activity and colour descriptives.

| ColourEnv | Mean | Std. Error | 95% Confidence Interval | |
|-----------|------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 2.59 | .05 | 2.45 | 2.73 |
| Red | 2.48 | .04 | 2.36 | 2.60 |
| Blue | 2.69 | .05 | 2.55 | 2.84 |
| Green | 2.57 | .04 | 2.44 | 2.69 |
| Yellow | 2.71 | .07 | 2.52 | 2.90 |

A repeated measures ANOVA was conducted which found a main effect of colour on F3, FZ and F3 beta activity $F(4, 16) = 6.04, p = .004$.

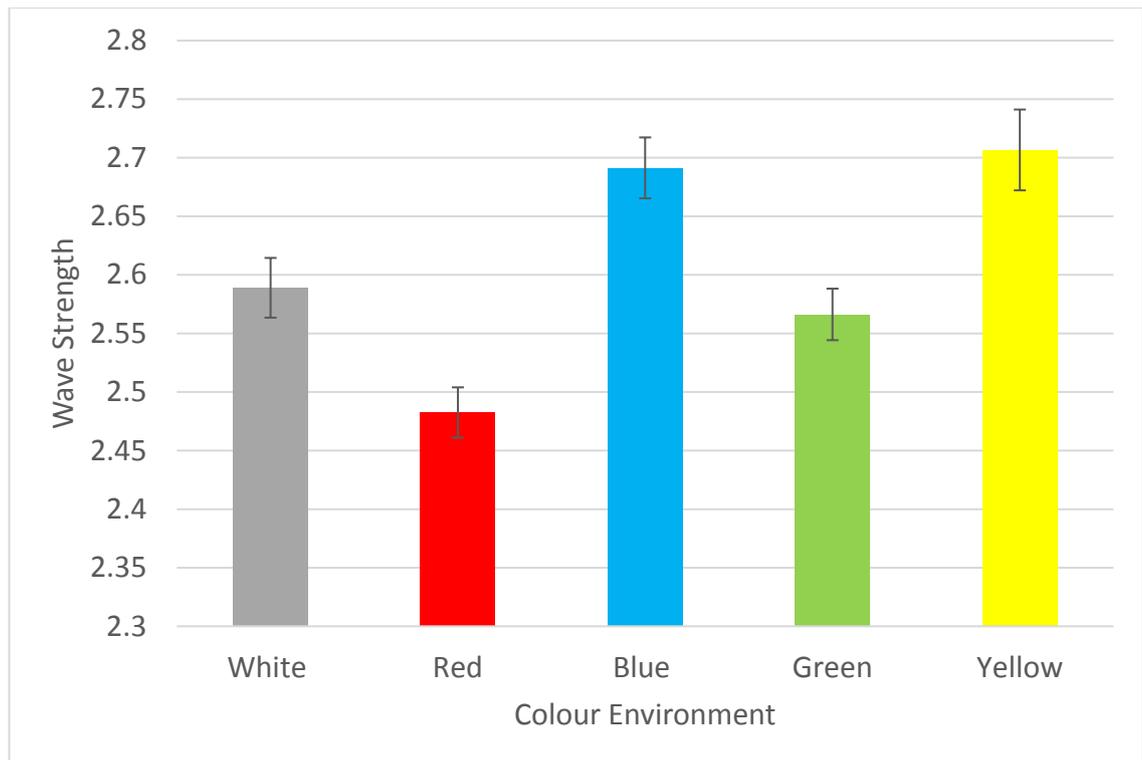


Figure 56: Frontal Beta wave and colour comparison.

A Bonferroni post-hoc test (see appendix G) was used to find the directional nature of the main effect of colour environment. More activity was seen in Blue ($M = 2.69$ $SD = .115$) than White ($M = 2.59$ $SD = .113$ $p = .008$), red ($M = 2.48$ $SD = .097$ $p = .034$) and green ($M = 2.57$ $SD = .099$ $p = .041$).

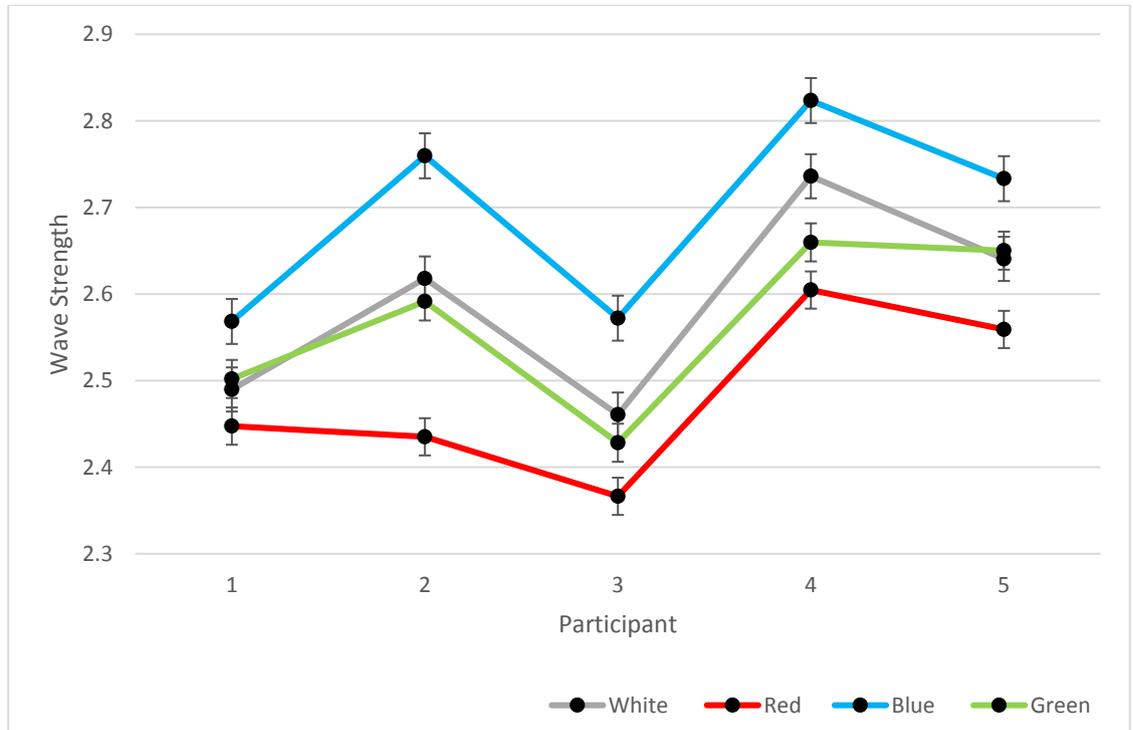


Figure 57: Comparison of white, red, blue and green frontal Beta waves across participants.

Lower activity was seen in Red ($M = 2.48$ $SD = .097$) than Blue ($M = 2.69$ $SD = .115$ $p = .034$) and yellow ($M = 2.71$ $SD = .155$ $p = .047$).

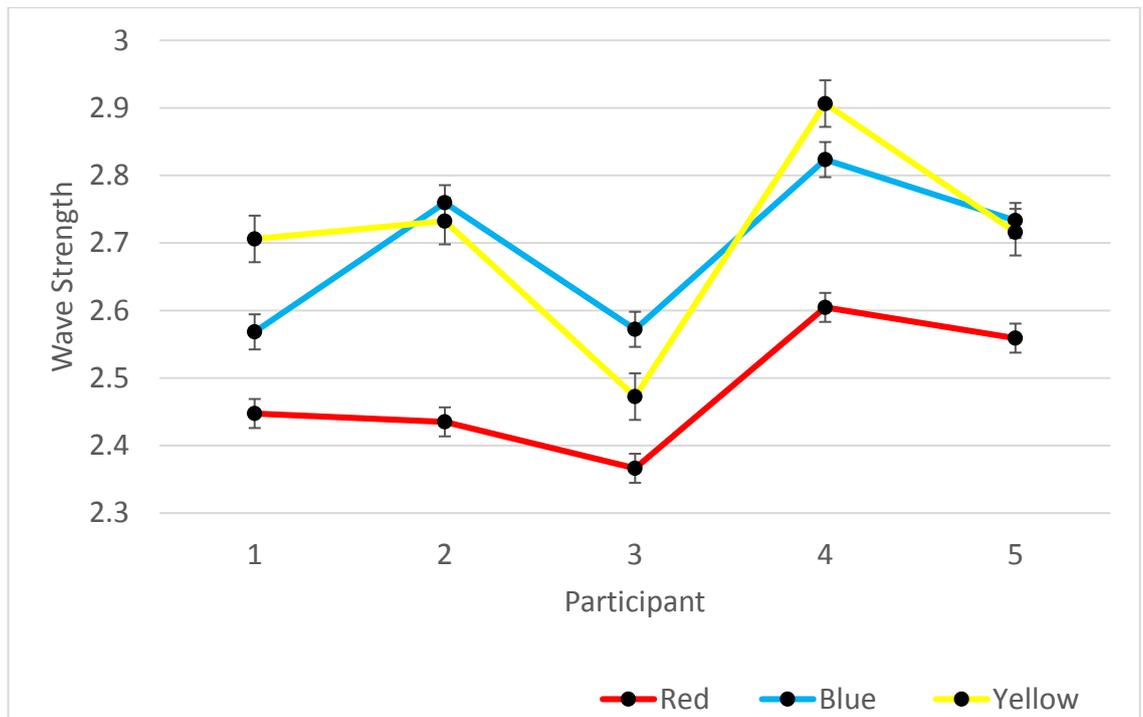


Figure 58: Comparison of red, yellow and blue frontal Beta waves across participants.

Frontal (F3, FZ and F3) Alpha waves

Table 31: Frontal Alpha activity and colour descriptives.

| ColourEnv | Mean | Std. Error | 95% Confidence Interval | |
|-----------|------|------------|-------------------------|-------------|
| | | | Lower Bound | Upper Bound |
| White | 3.00 | .07 | 2.80 | 3.21 |
| Red | 2.79 | .04 | 2.69 | 2.90 |
| Blue | 3.11 | .08 | 2.88 | 3.33 |
| Green | 2.92 | .04 | 2.82 | 3.03 |
| Yellow | 3.11 | .10 | 2.84 | 3.38 |

A repeated measures ANOVA was conducted which found a main effect of colour on F3, FZ and F3 Alpha activity $F(4, 16) = 10.04, p = <.001$.

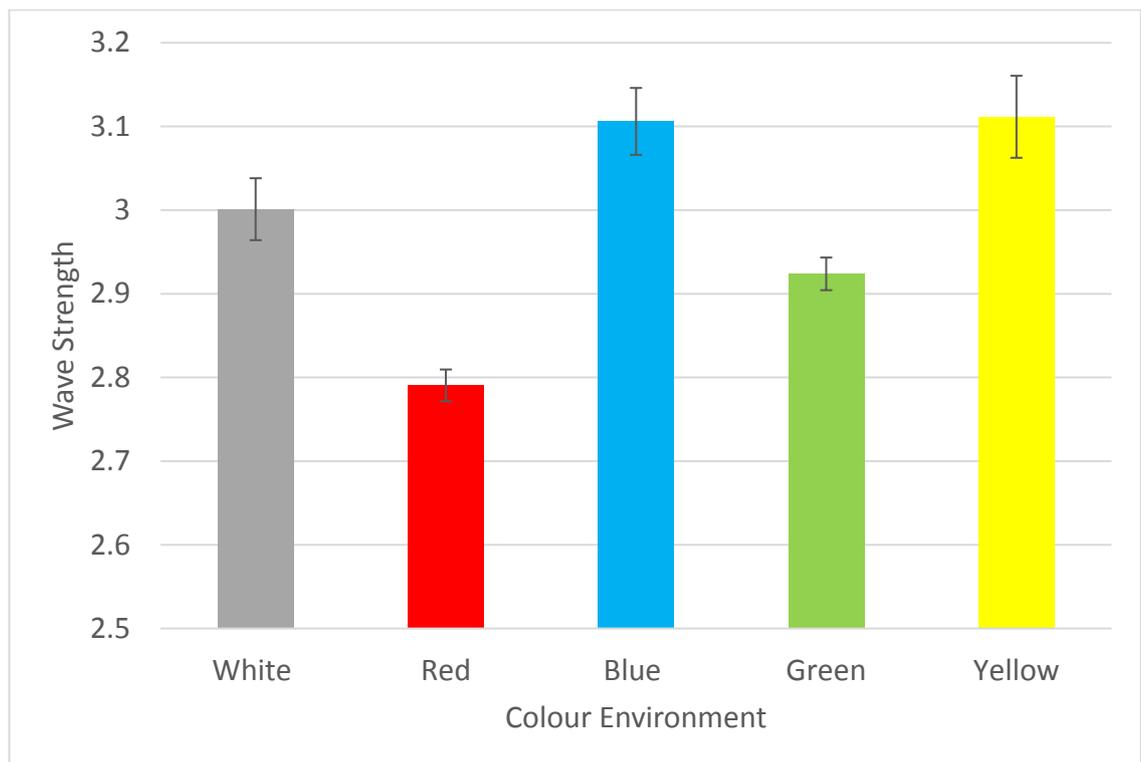


Figure 59: Frontal Alpha wave and colour comparison.

A Bonferroni post-hoc test (see appendix G) was used to find the directional nature of the main effect of colour environment. More activity was seen in Green ($M = 2.92$ $SD = .087$) than Red ($M = 2.79$ $SD = .085$ $p = .003$).

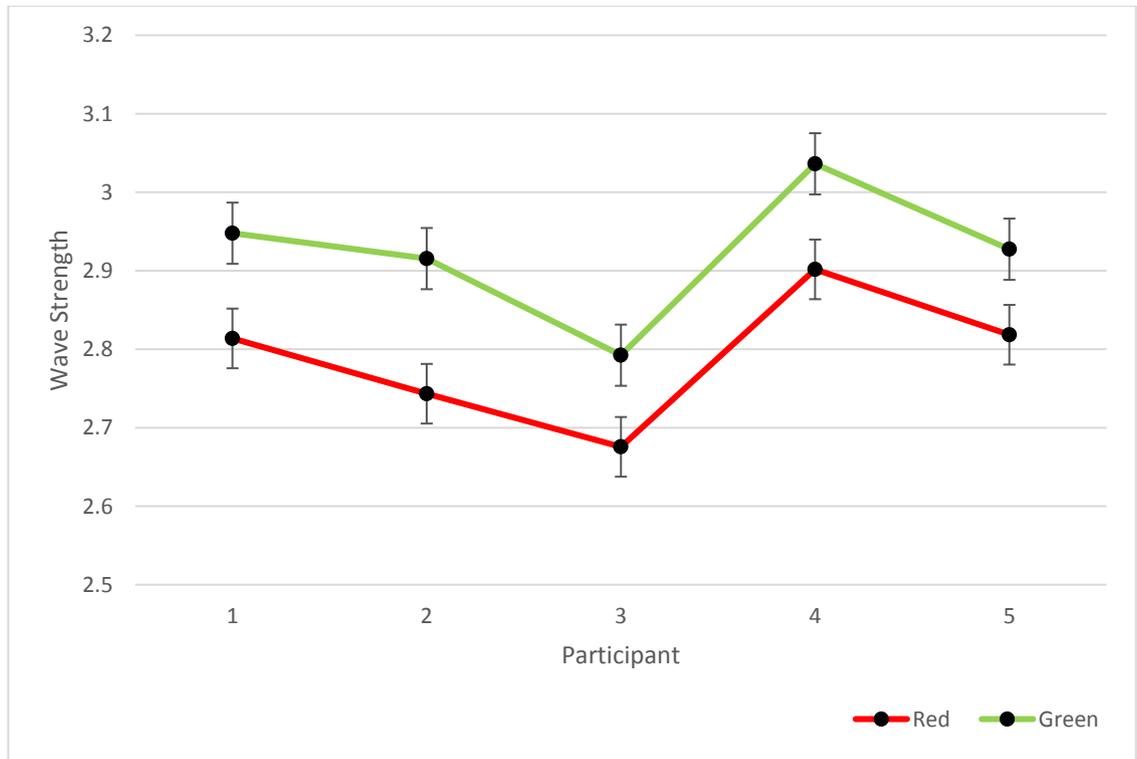


Figure 60: Comparison of green and red frontal alpha waves across participants.

5. Discussion and Conclusions

5.1 Study 1: Personality Based Approach

This experiment used personality based methodologies to understand the relationship between colour and impulsivity. Predictions were made on the premises of the state-trait anger theory (Spielberger, Krasner & Solomon, 1988) which breaks down impulsivity into two sub-constructs, state and trait. State impulsivity referring to a subject's short-term transitory state at any given time, which can be affected by immediate factors (in this case the change of colour) altering an individual's response to an event. Whereas trait impulsivity, a more enduring personality characteristic would remain stable over the longer term. This results in more predictable behavioural outcomes across a range of situations (Deffenbacher *et al.*, 1996).

The results from this study mean that H0a cannot be rejected but H0b can be rejected. Repeated measures ANOVAs found no significant changes in reported impulsivity levels in a state measure (BIS 11) however there were differences in trait measures. A significant main effect of colour was found on impulsivity score in Assessing Mood in Daily Life $F(4, 96) = 7.14, p < .001$. This highlights the dissociation between state and trait impulsivity and how personality traits may be affected differently, Therefore H1: may be accepted. The findings support work by Swann *et al.* (2009) and Christodoulou *et al.*, (2006) who obtained similar results when studying individuals with impulsive related psychopathologies, this highlights the importance of making distinctions between impulsive sub-components.

To understand the directional nature of the significant main effect, a Bonferroni post-hoc test was used. Red was causing higher impulsive feelings. In the Assessing Mood in Daily Life scale low scores mean increased impulsive feelings. Red (M =37.7600, SD =20.75508) was significantly lower in score than White (M = 54.56, SD =19.39) ($p = .001$), Green (M =55.0400, SD = 16.86 $p = .001$) & Blue (M =56.4800, SD =19.26 $p = .008$).

There are several possible reasons for this: The 'arousing' effect of red, learned responses associated with the colour and also potential evolutionary arguments. An associative response to colour is caused by past experiences which have an effect on an individual's physiological arousal, a process known as 'associative learning'. A stimulus may be paired to a particular colour for example red with danger, blood and pain. After several similar associations future exposures to that colour elicits the same neurological response to the paired stimulus but with only the colour being present (Bierley, 1985). In the case of the evolutionary argument this association is present from birth with no learned associations necessary. Individuals acting more on instinct than evaluating the situation could rely more on these mechanisms and therefore have increased impulsiveness under red light as explained by the Dual Process Theory of automatic vs. controlled cognitive processing which proposes that mental operations are done in one of two ways, being either automated or controlled. Generally speaking, processes that are automatic require previous experience or informal heuristics of a response and do not use higher levels of cognition (Amsel *et al.*, 2009) and the cognitive-experiential self-theory which explains these two different ways of information processing: analytical-rational and intuitive-experiential (Epstein 1994, 1996).

An alternative explanation for this effect is that red increases arousal which may in turn increase impulsiveness. The arousing effect of red light has been reported since the 1960s to cause a feeling of stimulation and excitement, supporting a more general concept that longer wave length colours cause higher arousal (Wilson, 1966). Duan (2017) investigated the direct links between colour, impulsivity, arousal and emotion using computer based tasks, questionnaires and psychophysical measurements. She discovered that red did indeed increase arousal levels. There was also a clear trend that red and orange chroma increased impulsivity, with more intense chroma levels having the strongest effect. However, when comparing impulsiveness and arousal across colours, There was evidence that arousal/impulsive did not show the expected correlations and should be viewed separately.

Surprisingly there was no significant effect of blue light. Contrary to a large body of opinion pieces which suggest that blue has a relaxing or calming effect on mood and

personality traits (Color Psychology: How Colors Impact Moods, Feelings and Behaviors, 2016) and growing evidence in the scientific community that short wavelength (blue) light has mood enhancing effects in humans: increase alertness, mood and cognitive function via the non-image forming neuropathways. It has even been suggested as a non-pharmacological treatment for depression (Ekström & Beaven, 2014).

The second significant effect found that base Impulsivity had an ongoing effect of impulsivity scores. Base impulsivity was defined by the results of BIS 11 (scores higher than 70 were considered high impulse, lower were considered low. Questionnaire 2: SIS $F(1, 21) = 4.94$, $p = .037$ and Q3 Momentary Impulsivity Scale $F(1, 21) = 6.97$, $p = .015$ both showed all showed that high and low impulsive participants have matching scores to that of BIS 11 . This means H_{0c} can be rejected and H_2 accepted providing evidence that the BIS measure of impulsivity is valid across a range of questionnaires from trait to state measures. Therefore H_{0c} can be rejected and H_3 can be accepted. Finally the last significant effects were found in Gender differences; An interaction between gender, base impulsiveness and BIS scores $F(1, 21) = 4.75$, $p = .041$. The high impulsive group of females were considerably more impulsive than males in the same group. In MIS females had higher scores than males $F(1, 21) = 7.48$, $p = .012$ therefore H_{0d} can be rejected and H_3 accepted.

Females have often been reported to have greater sensitivity to colour more than males. Abramov (2012) asked men and women to break down colours into different hues and to assign a percentage to red, yellow, green, and blue, women were more adept at distinguishing between subtle gradations. However, men were better than women at perceiving changes in brightness across space, fine details and rapid movement than women. Duan (2017) also found that the effect of colour was stronger on females than male in computer based tasks looking at colours effect on impulsiveness and arousal. In hunter-gatherer society, there were gender specific roles which may explain these differences. Females were gathers and needed to recognise berries in foliage or the species of a fruit through its colour. Males went

out to hunt and needed better visual-spatial skills. This evolved characteristics may affect our acumen today.

5.2 Study 2: Behavioural Based Approach

This experiment used behavioural based methodologies to understand the relationship between colour and impulsivity. It was hypothesised that participant's behaviour relating to impulsivity would be affected by the colour of the environment.

Two behavioural tasks were used the Go/ No Go Task, a test of behavioural inhibition and the BART task measuring levels of risk taking both of which found significant effects of colour H_0 can be rejected and H_4 accepted. Results from the Go/ No Go Task showed a significant main effect of colour and reaction time $F(4, 136) = 17.35$, $p = <.001$. Reaction times in the blue condition blue ($M = 318.295$ $SD = .81684$) were faster than white ($M = 340.451$ $SD = 1.82098$ $p = .013$), red ($M = 361.495$ $SD = .94202$ $p = <.001$) and yellow ($M = 340.565$ $SD = .74134$ $p = <.001$).

Faster reaction time in blue with no increase in task error shows an improvement in task performance. This could indicate better attention and cognitive control. Viola *et al.* (2008) compared white light (4000 K) with blue-enriched white light (17000 K). Results found improvement in subjective measures of alertness, positive mood, performance, evening fatigue, irritability and concentration. In addition to this daytime sleepiness was reduced and the quality of subjective nocturnal sleep. Recent research using fMRI has shown that exposure to blue light, when compared with green (Vandewalle *et al.*, 2007) or violet (Vandewalle *et al.*, 2007) light is more effective in enhancing responses in memory tasks. This would suggest that the blue spectral composition of light may enhance alertness and performance in certain tasks, although the effect this has on impulsiveness is still unclear.

Reaction times were slower in the red condition ($M = 361.495$ $SD = .94202$) than blue ($M = 318.295$ $SD = .81684$ $p = <.001$) green ($M = 325.050$ $SD = 1.34914$ $p = <.001$) and yellow ($M = 340.565$ $SD = .74134$ $p = .004$) this suggests a reduction in task performance. The cognitive depletion theory of impulsivity deems self-control as an inner capacity

which uses a limited internal resource store. There are certain factors which accelerate or reduce the cognitive depletion effect. Exposure to blue has been reported to improved mood, a factor which has been found to helps maintain the cognitive store (Tice, 2007) manifested in better reaction times. Performance deficits due to mental fatigue is associated with a deterioration of information processing functions (attention and cognitive control). To sustain task performance, subjects are required to regulate their cognitive resources (Kok, 1997). Red is well documented as being a stimulating/arousing colour (Nakshian, 1964; Küller, 2009; Valdez 1994) over-arousal exhausts cognitive resources and result in slower reaction times. It is worth noting that the low instances of error rates indicate that the task was too simple. Stronger misleading cues and less recovery time between trials may be enough to identify different error rates between conditions.

During the second behavioural task (BART) most measures came back as non-significant however there was a significant main effect of colour on balloon bursts $F(4, 136) = 2.8, p = .029$. It was found that there were more bursts in blue ($M = 4.00$ $SD = 2.45$) than white ($M = 2.74$ $SD = 1.09$ $p = .018$).

Studies within behavioural psychology and neuro-economics have determined that impulsivity within intertemporal choice is best described as 'choosing smaller more immediate rewards rather than larger later ones' (Thaler, 1997). In the BART task impulsivity would present itself as a participant trying to get the most money in each trial (resulting in more bursts) rather than lower pumps on each trial but having less balloon burst across the whole of the task which would bring back a larger over all return. The increase of bursts in the blue condition therefore suggests higher levels of risking taking behaviour and potentially impulsiveness. There is limited research around the effect of blue light on risk taking; these results suggest that further investigation is needed.

5.3 Study 3: Neurological Based Approach

This experiment used neurological based methodologies to understand the relationship between colour and impulsivity. It was hypothesised participant's brain

activity relating to impulsiveness would change while completing the behavioural tasks depending on the colour of the environment. A summary of significant changes can be found in tables 32 & 33 these results indicate that H0f can be rejected and H5&6 accepted.

Table 32: Total brain wave activity results.

| Main Effect | Directional |
|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Theta $F(4, 16) = 5.63, p = .005.$ | Non-significant |
| Alpha $F(4, 16) = 24.33, p = <.001$ | Red (M = 2.74 SD = .068) activity was significantly lower than white (M = 2.99 SD = .097; $p = .025$) blue (M = 3.08 SD = .11; $p = .032$) and Yellow (M = 3.07 SD = .16; $p=.031$). |
| Beta $F(4, 16) = 14.28, p = <.001.$ | Red (M = 2.40 SD = .078) activity was significantly lower than white (M = 2.51 SD = .078; $p = .010$) and blue (M = 2.57 SD = .10; $p = .033$). |

Table 33: Frontal brain wave activity results

| Main Effect | Directional |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Theta $F(4, 16) = 6.04, p = .004.$ | Non-significant |
| Beta $F(4, 16) = 6.04, p = .004.$ | More activity in Blue (M = 2.69 SD = .115) than White (M = 2.59 SD = .113 $p = .008$), red (M = 2.48 SD = .097 $p = .034$) and green (M = 2.57 SD = .099 $p = .041$). Lower activity was seen in Red (M = 2.48 SD = .097) than Blue (M = 2.69 SD = .115 $p = .034$) and yellow (M = 2.71 SD = .155 $p = .047$). |
| Alpha $F(4, 16) = 10.04, p = <.001.$ | More activity was seen in Green (M = 2.92 SD = .087) than Red (M = 2.79 SD = .085 $p = .003$). |

Traditionally it has been thought that longer light wavelength colours (yellow, orange and red) result in greater neuronal activation whereas shorter wavelengths (green and blue) have a sedative effect (Wright & Rainwater, 1962). Spectral power studies using qEEG and computer-aided signal analysis have consistently found that impulsive pathologies have increased EEG power in theta and beta bands. The majority of impulsive pathologies are associated with increased slow wave activity, suggesting they share the same underlying mechanism. This could be explained by low cortical arousal, resulting in failures in executive control, a notion supported by Barratt (1985). When analysing high frequency EEG activity, individuals suffering from impulsive related pathologies exhibited increases in beta activity (Pollock *et al.*, 1992; Newton *et al.*, 2003; Flor-Henry *et al.*, 1991; Koelsch *et al.*, 2008) resulting in hyper-excitability in the central nervous system (Rangaswamy *et al.*, 2002). From the findings of previous research this suggests two mechanisms which result in higher levels of impulsiveness, high, low band wave activity resulting in poor executive control and high fast band wave activity resulting in hyper-excitability. The results in this study show that red produces lower levels of beta waves in both total brain activity and frontal regions. With increases in beta activity in blue light. This suggests that blue light is causing higher levels of cortical activity and possible hyper-excitability resulting in increased impulsiveness. The results for the slower (theta) waves were non-conclusive as post-hoc tests did not reveal any particular colour being significantly different so no inferences can be drawn apart from the need to conduct a larger scale study to confirm findings.

An additional observation is that alpha, beta and theta brain wave activity appears correlated across colours. This may be an artefact of a small experimental sample but it is interesting to note that the statistical significance of total vs frontal variation in wave activity is different, despite an apparent similarity in wave activity. More statistically significant beta activity was seen in frontal regions (M = 2.69 SD = .115) than white (M = 2.59 SD = .113 p = .008), red (M = 2.48 SD = .097 p = .034) and green (M = 2.57 SD = .099 p = .041) whereas this was not the case when looking at total brain activation. This was also the case in total beta activity in red light being lower (M = 2.40 SD = .078) than white (M = 2.51 SD = .078; p = .010) and blue (M = 2.57

SD = .10; $p = .033$) in general brain activity that did not appear solely the frontal regions.

The capacity to measure event related potentials (ERP) would be of benefit in future neurological studies, the EEG system used in this study is lacking a component which would make this possible. Results containing ERP data capture specific timing of information processing events and would provide a better understanding the effect colour is having on impulsive related brain activity.

5.4 Perspective Comparison

The comparison of perspective used in this work gives good overall insight but mixed messages. It is widely accepted that impulsivity is multifactorial (Buss & Plomin, 1975), when blanket impulsivity measures are used they may actually be measuring different sub-types of the concept. Trying to combine each perspective may suffer from this same drawback but is a good starting point for future research. Going forward studies should focus on identifying the facets of impulsivity and testing them individually before making inferences about the whole concept.

Perspectives in agreement:

Behavioural and neurological approaches show similar results regarding blue light, blue bursts in BART and the associated brain wave changes suggest an increase in impulsiveness. Fast reaction times in the go no/ go task although initially show better performance could also indicate reduced behavioural inhibition. The best way to test this would be to create a more complex go/no task which would have higher error rates and then observes if these were especially high in blue light.

Perspectives in disagreement:

The personality (self-report) measures showed that red was causing increased levels of impulsive feelings, with no statistically significant differences in blue. This is in contrast to reductions or non-significant changes in the other approaches. People may feel more impulsive under red light but may act differently in both terms of behaviour and in their neurological responses to the colour. This difference may highlight how alternative perspectives measure each sub-construct of impulsiveness.

5.5 Future Research

Spectral composition & Luminosity of conditions

An important area of improvement in this study is the spectra used in two of the colour conditions. In the early stages of the research an older lighting system was used which had limited colour and luminance production, this system was then replaced with a new system which could allow for many more colour configurations. To keep conditions the same across all testing and participants the original lighting for blue & yellow colours was replicated on the new system (figure 35 & figure 37) This issue did not affect the white (figure 29) red (figure 31) and green conditions (figure 33) which already had a relatively narrow spectral band. The luminance in the blue condition was slightly lower than other conditions due to the limitation of the older system. In future work it is advisable to use single wavelength stimuli in an identical luminosity to be able to have higher accuracy in determining how each wavelength of light effects participants; mood, behaviour and brain activity (see figures 61 & 62 for the proposed improvements).

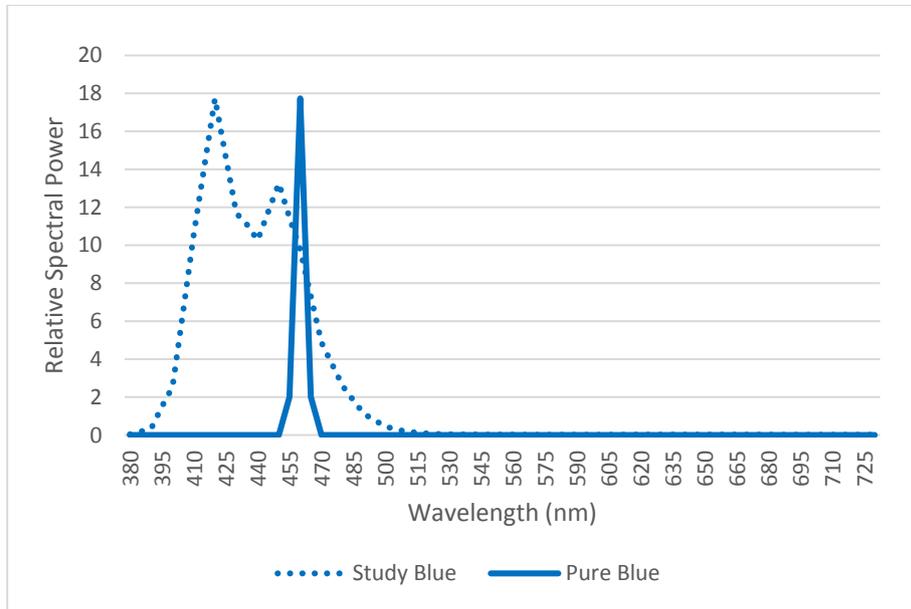


Figure 61: Ideal blue condition spectral distribution

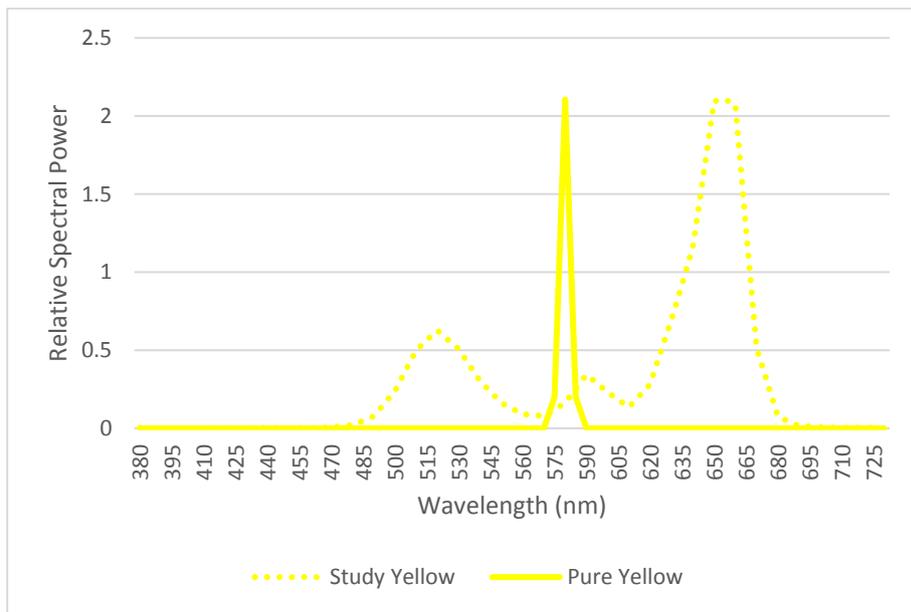


Figure 62: Ideal yellow condition spectral distribution

Sample improvements

Another area of expansion for this research would be to include a larger healthy sample of participants and also a new group of those suffering from impulsive pathologies in the participant pool. The current sample size was determined by availability of resources including: time, human resources and money for

participation. It is generally accepted that the sample size needs to be large enough to reflect important variations in the population, but small enough to allow for intensive study methods, aiming for at least 30 people in each group of interest (Hardon et al ., 2004). In addition to this, knowing how sufferers of ADHD, anxiety disorders, and suicidal ideation respond compared to a 'healthy' population would provide valuable insight. There are however ethical concerns with this as potentially manipulating the emotions/behaviour/neurological responses of anyone suffering from these conditions could be at their detriment.

Concluding statements

1. Although there is some evidence to suggest that blue light increases impulsive behaviour and brain activity there is not enough evidence to make accurate inferences about the effect of colour on impulsivity, these studies should be used as the basis for work going forward in this field.
2. Impulsivity shouldn't be viewed as a blanket construct. Its subcontracts are complex and have varying effects on behaviour which may make it unclear how changes in behaviour are manifested.
3. Until further empirically sound research is conducted interventions relating to the effect of coloured environments on serious impulsive pathologies should not be implemented, especially in the case of blue light reducing instances of violent crime and suicide.

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Appendix

Appendix A: Questionnaires 1

People differ in the ways they act and think in different situations. This is a test to measure some of the ways in which you act and think. Read each statement and put an X on the appropriate circle on the right side of this page. Do not spend too much time on any statement. Answer quickly and honestly.

| Rarely/Never | Occasionally | Often | Almost Always/Always |
|----------------------------------------------------------|--------------|-------|----------------------|
| ① | ② | ③ | ④ |
| 1. I plan tasks carefully. | | | ① ② ③ ④ |
| 2. I do things without thinking. | | | ① ② ③ ④ |
| 3. I make-up my mind quickly. | | | ① ② ③ ④ |
| 4. I am happy-go-lucky. | | | ① ② ③ ④ |
| 5. I don't "pay attention." | | | ① ② ③ ④ |
| 6. I have "racing" thoughts. | | | ① ② ③ ④ |
| 7. I plan trips well ahead of time. | | | ① ② ③ ④ |
| 8. I am self controlled. | | | ① ② ③ ④ |
| 9. I concentrate easily. | | | ① ② ③ ④ |
| 10. I save regularly. | | | ① ② ③ ④ |
| 11. I "squirm" at plays or lectures. | | | ① ② ③ ④ |
| 12. I am a careful thinker. | | | ① ② ③ ④ |
| 13. I plan for job security. | | | ① ② ③ ④ |
| 14. I say things without thinking. | | | ① ② ③ ④ |
| 15. I like to think about complex problems. | | | ① ② ③ ④ |
| 16. I change jobs. | | | ① ② ③ ④ |
| 17. I act "on impulse." | | | ① ② ③ ④ |
| 18. I get easily bored when solving thought problems. | | | ① ② ③ ④ |
| 19. I act on the spur of the moment. | | | ① ② ③ ④ |
| 20. I am a steady thinker. | | | ① ② ③ ④ |
| 21. I change residences. | | | ① ② ③ ④ |
| 22. I buy things on impulse. | | | ① ② ③ ④ |
| 23. I can only think about one thing at a time. | | | ① ② ③ ④ |
| 24. I change hobbies. | | | ① ② ③ ④ |
| 25. I spend or charge more than I earn. | | | ① ② ③ ④ |
| 26. I often have extraneous thoughts when thinking. | | | ① ② ③ ④ |
| 27. I am more interested in the present than the future. | | | ① ② ③ ④ |
| 28. I am restless at the theater or lectures. | | | ① ② ③ ④ |
| 29. I like puzzles. | | | ① ② ③ ④ |
| 30. I am future oriented. | | | ① ② ③ ④ |

Appendix A: Questionnaires 2

In the following, there are sentences related with how you have behaved in different situations in the last month. Check the corresponding box with an X to indicate how often they have occurred in your case. Answer quickly and honestly.

Rarely/Never Occasionally Often Almost Always/Always
① ② ③ ④

1. I seek activities where I obtain rapid pleasure, even if they are harmful. 1 2 3 4
2. I generally fall into temptations that make it hard for me to fulfil a commitment. 1 2 3 4
3. I seek immediate benefits instead of waiting for something better later on. 1 2 3 4
4. I continue doing certain pleasurable activities even if the others warn me that they are harmful for me. 1 2 3 4
5. When I have a craving for something, I go for it immediately, without being able to wait. 1 2 3 4
6. I obtain more pleasure transgressing than controlling my actions. 1 2 3 4
7. It is hard for me to control my reactions even if I do not get what I want. 1 2 3 4
8. It is hard for me to stop doing something when I see that I am making a mistake. 1 2 3 4
9. I have automatic reactions that I cannot avoid. 1 2 3 4
10. If I do something and do not obtain the results I expects, it is hard for me to do something else. 1 2 3 4
11. I usually react in the same way, even if it is not the appropriate time or place. 1 2 3 4
12. I do not restrain my reactions no matter how much others tell me to stop. 1 2 3 4
13. I repeat the same way of acting many times even if it does not achieve what I am seeking. 1 2 3 4
14. I generally make mistakes because I react so quickly that I do not pay sufficient attention to important details. 1 2 3 4
15. When something unexpectedly occurs, I act without considering the consequences. 1 2 3 4
16. I draw erroneous conclusions because I do not wait for the appropriate time. 1 2 3 4
17. Sometimes I do not pay attention to the immediate consequences of my actions. 1 2 3 4
18. I respond before someone has finished asking me a question. 1 2 3 4
19. In some situations, I do not wait long enough and act prematurely. 1 2 3 4
20. I act without thinking that others may get angry because of what I do. 1 2 3 4

Appendix A: Questionnaires 3 & 4

In the following, there are sentences related with how you feel.
Check the corresponding box with an X. Answer quickly and honestly.

Stongly Disagree Disagree Agree Strongly Agree
① ② ③ ④

I say things without thinking. ① ② ③ ④
I feel like spending money ① ② ③ ④
I feel impatient. ① ② ③ ④
I make "spur of the moment" decisions. ① ② ③ ④

In the following, there are words related to how people can feel.
Place an X on the line where appropriate.

At this moment I feel:

Awake 5 4 3 2 1 0 1 2 3 4 5 Tired
Discontent 5 4 3 2 1 0 1 2 3 4 5 Content
Agitated 5 4 3 2 1 0 1 2 3 4 5 Calm
Full of Energy 5 4 3 2 1 0 1 2 3 4 5 Without Energy
Well 5 4 3 2 1 0 1 2 3 4 5 Unwell
Tense 5 4 3 2 1 0 1 2 3 4 5 Relaxed

Appendix B: Ethical approval certificate study one

PVAC & Arts joint Faculty Research Ethics Committee
University of Leeds

20 April 2018

Dear Nicholas

Title of study **How does colour effect impulsivity; A personality based approach**

Ethics reference **LTDESN-046**

I am pleased to inform you that the above application for light touch ethical review has been reviewed by a School Ethics Representative of the PVAC and Arts (PVAR) joint Faculty Research Ethics Committee. I can confirm a favourable ethical opinion on the basis of the application form as of the date of this letter. The following documentation was considered:

| Document | Version | Date |
|-------------------------------------------|---------|----------|
| LTDESN-046 LightTouchEthicsFormFinal.docx | 1 | 20/04/16 |
| LTDESN-046 response1.txt | 1 | 04/05/16 |

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval as all changes must receive ethical approval prior to implementation. The amendment form is available at <http://ris.leeds.ac.uk/EthicsAmendment>.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice

period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at <http://ris.leeds.ac.uk/EthicsAudits>.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie

Senior Research Ethics Administrator, Research & Innovation Service

On behalf of Dr Kevin Macnish, Chair, [PVAR FREC](#)

CC: Student's supervisor

Appendix C: Ethical approval certificate study two

PVAC & Arts joint Faculty Research Ethics Committee

University of Leeds

20 April 2018

Dear Nicholas

Title of study **How does colour effect impulsivity; A behavioural based approach**

Ethics reference **LTDESN-055**

I am pleased to inform you that the above application for light touch ethical review has been reviewed by a School Ethics Representative of the PVAC and Arts (PVAR) joint Faculty Research Ethics Committee. I can confirm a favourable ethical opinion on the basis of the application form as of the date of this letter. The following documentation was considered:

| Document | Version | Date |
|------------------------------------|---------|----------|
| LTDESN-055 Consent Form.pdf | 1 | 05/10/16 |
| LTDESN-055 ethics application.docx | 1 | 17/10/16 |

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval as all changes must receive ethical approval prior to implementation. The amendment form is available at <http://ris.leeds.ac.uk/EthicsAmendment>.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. You will be given a two week notice period if your

project is to be audited. There is a checklist listing examples of documents to be kept which is available at <http://ris.leeds.ac.uk/EthicsAudits>.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie

Senior Research Ethics Administrator, Research and Innovation Service

On behalf of Dr Kevin Macnish, Chair, [PVAR FREC](#)

Appendix D: Ethical approval certificate study three

PVAC & Arts joint Faculty Research Ethics Committee

University of Leeds

13 December 2016

Dear Nicholas

Title of study **How does colour effect impulsivity; A neurological based approach.**

Ethics reference **LTDESN-061**

I am pleased to inform you that the above application for light touch ethical review has been reviewed by a School Ethics Representative of the PVAC and Arts (PVAR) joint Faculty Research Ethics Committee. I can confirm a favourable ethical opinion on the basis of the application form as of the date of this letter. The following documentation was considered:

| Document | Version | Date |
|-------------------------------------|---------|----------|
| LTDESN-061 LightTouchEthicsForm (2) | 1 | 22/11/16 |

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval as all changes must receive ethical approval prior to implementation. The amendment form is available at <http://ris.leeds.ac.uk/EthicsAmendment>.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at <http://ris.leeds.ac.uk/EthicsAudits>.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Victoria Butterworth

Research Ethics Administrator, Research and Innovation Service

On behalf of Dr Kevin Macnish, Chair, [PVAR FREC](#)

CC: Student's supervisor

Appendix E: Information Sheet

This is PhD project extension originating from The School of Design at the University of Leeds. The experiment investigates how environment effect certain aspects of behaviour. This study will take place in a specially designed room. The testing session will last for approximately 30 minutes. This sheet is designed to give you enough information about the study for you to be able to make an informed decision whether you would like to participate.

In this experiment you will be asked to repeat two computer based tasks which take approximately 4 minutes each. Within these tasks you will have to respond to visual cues through key presses. Once you have finished you will be debriefed and have the opportunity to ask further questions on the research.

The study has been approved by the ethics committee of the design school and is subject to ethical guidelines set out by the British Psychological Society. Participation in this study is voluntary. Moreover, if you decide to take part, you are free to withdraw at any time and do not need to give a reason. A unique code will be the only identifier that is stored with your data. Although data from the experiment will be used in the follow up report and may be used for other academic publications you will not be identifiable in these.

If anything is unclear about the nature of the experiment or you would like more information please ask the experimenter now.

If you have any ethical concerns about this experiment you should contact:

Stephen Westland
Professor of Colour
Science University of
Leeds

Leeds, LS2 9JT, UK

S.Westland@leeds.ac.uk

Appendix F: Consent Form

1. I give my informed consent to participate in this study, and for the publication of my results providing the information is kept anonymous.
2. I have been informed of the general purpose of this study.
3. I have been given a copy of the participant information sheet, which I have read and understood.
4. I have been told that I will be informed about the full nature of the study upon completion if I wish.
5. I have been informed that this study has been approved by The Design School Ethics Committee.
6. I have been informed that I am free to withdraw from the study at any time without having to justify my actions.
7. I am aware that this study is conducted in a controlled space and may be unsuitable for those who suffer from claustrophobia or epilepsy.
8. I agree to take part in this study.

Name:

Gender:

Birthdate:

Ethnicity:

Signature:

Date:

Appendix G: Pairwise Comparisons

Experiment 1, Questionnaire 4 Environment colour and Score.

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | 16.800* | 3.533 | .001 | 5.882 | 27.718 |
| | 3 | -1.920 | 4.340 | 1.000 | -15.332 | 11.492 |
| | 4 | -.480 | 4.127 | 1.000 | -13.234 | 12.274 |
| | 5 | 4.640 | 4.881 | 1.000 | -10.444 | 19.724 |
| 2 | 1 | -16.800* | 3.533 | .001 | -27.718 | -5.882 |
| | 3 | -18.720* | 4.876 | .008 | -33.788 | -3.652 |
| | 4 | -17.280* | 3.779 | .001 | -28.958 | -5.602 |
| | 5 | -12.160 | 4.305 | .094 | -25.464 | 1.144 |
| 3 | 1 | 1.920 | 4.340 | 1.000 | -11.492 | 15.332 |
| | 2 | 18.720* | 4.876 | .008 | 3.652 | 33.788 |
| | 4 | 1.440 | 3.232 | 1.000 | -8.549 | 11.429 |
| | 5 | 6.560 | 4.091 | 1.000 | -6.085 | 19.205 |
| 4 | 1 | .480 | 4.127 | 1.000 | -12.274 | 13.234 |
| | 2 | 17.280* | 3.779 | .001 | 5.602 | 28.958 |
| | 3 | -1.440 | 3.232 | 1.000 | -11.429 | 8.549 |
| | 5 | 5.120 | 2.962 | .968 | -4.035 | 14.275 |
| 5 | 1 | -4.640 | 4.881 | 1.000 | -19.724 | 10.444 |
| | 2 | 12.160 | 4.305 | .094 | -1.144 | 25.464 |
| | 3 | -6.560 | 4.091 | 1.000 | -19.205 | 6.085 |

| | | | | | |
|---|--------|-------|------|---------|-------|
| 4 | -5.120 | 2.962 | .968 | -14.275 | 4.035 |
|---|--------|-------|------|---------|-------|

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Experiment 2, Go / No-Go Reaction time and Colour Env.

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | -21.044 | 8.355 | .166 | -46.126 | 4.037 |
| | 3 | 22.155* | 6.339 | .013 | 3.125 | 41.186 |
| | 4 | 15.400 | 6.454 | .227 | -3.973 | 34.774 |
| | 5 | -.114 | 6.002 | 1.000 | -18.131 | 17.903 |
| 2 | 1 | 21.044 | 8.355 | .166 | -4.037 | 46.126 |
| | 3 | 43.200* | 4.720 | .000 | 29.032 | 57.368 |
| | 4 | 36.445* | 5.489 | .000 | 19.967 | 52.922 |
| | 5 | 20.930* | 5.351 | .004 | 4.867 | 36.994 |
| 3 | 1 | -22.155* | 6.339 | .013 | -41.186 | -3.125 |
| | 2 | -43.200* | 4.720 | .000 | -57.368 | -29.032 |
| | 4 | -6.755 | 4.318 | 1.000 | -19.718 | 6.208 |
| | 5 | -22.269* | 4.270 | .000 | -35.087 | -9.452 |
| 4 | 1 | -15.400 | 6.454 | .227 | -34.774 | 3.973 |
| | 2 | -36.445* | 5.489 | .000 | -52.922 | -19.967 |
| | 3 | 6.755 | 4.318 | 1.000 | -6.208 | 19.718 |
| | 5 | -15.514* | 4.042 | .005 | -27.649 | -3.379 |

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| 5 | 1 | .114 | 6.002 | 1.000 | -17.903 | 18.131 |
| | 2 | -20.930* | 5.351 | .004 | -36.994 | -4.867 |
| | 3 | 22.269* | 4.270 | .000 | 9.452 | 35.087 |
| | 4 | 15.514* | 4.042 | .005 | 3.379 | 27.649 |

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Experiment 2, BART balloon bursts and Colour Env.

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | -.686 | .414 | 1.000 | -1.927 | .556 |
| | 3 | -1.257* | .372 | .018 | -2.374 | -.140 |
| | 4 | -.514 | .396 | 1.000 | -1.703 | .675 |
| | 5 | -.886 | .414 | .395 | -2.127 | .356 |
| 2 | 1 | .686 | .414 | 1.000 | -.556 | 1.927 |
| | 3 | -.571 | .310 | .743 | -1.503 | .360 |
| | 4 | .171 | .351 | 1.000 | -.884 | 1.226 |
| | 5 | -.200 | .447 | 1.000 | -1.541 | 1.141 |
| 3 | 1 | 1.257* | .372 | .018 | .140 | 2.374 |
| | 2 | .571 | .310 | .743 | -.360 | 1.503 |

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| | 4 | .743 | .438 | .993 | -.573 | 2.059 |
| | 5 | .371 | .371 | 1.000 | -.744 | 1.486 |
| 4 | 1 | .514 | .396 | 1.000 | -.675 | 1.703 |
| | 2 | -.171 | .351 | 1.000 | -1.226 | .884 |
| | 3 | -.743 | .438 | .993 | -2.059 | .573 |
| | 5 | -.371 | .400 | 1.000 | -1.571 | .829 |
| 5 | 1 | .886 | .414 | .395 | -.356 | 2.127 |
| | 2 | .200 | .447 | 1.000 | -1.141 | 1.541 |
| | 3 | -.371 | .371 | 1.000 | -1.486 | .744 |
| | 4 | .371 | .400 | 1.000 | -.829 | 1.571 |

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Experiment 3, EEG total Alpha activity and Colour Env

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | .252* | .037 | .025 | .043 | .460 |
| | 3 | -.091 | .031 | .439 | -.268 | .085 |
| | 4 | .154 | .034 | .107 | -.037 | .346 |
| | 5 | -.083 | .036 | .810 | -.284 | .117 |

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| 2 | 1 | -.252* | .037 | .025 | -.460 | -.043 |
| | 3 | -.343* | .054 | .032 | -.647 | -.039 |
| | 4 | -.097 | .019 | .066 | -.202 | .008 |
| | 5 | -.335* | .052 | .031 | -.628 | -.042 |
| 3 | 1 | .091 | .031 | .439 | -.085 | .268 |
| | 2 | .343* | .054 | .032 | .039 | .647 |
| | 4 | .246 | .044 | .051 | -.001 | .492 |
| | 5 | .008 | .060 | 1.000 | -.329 | .346 |
| 4 | 1 | -.154 | .034 | .107 | -.346 | .037 |
| | 2 | .097 | .019 | .066 | -.008 | .202 |
| | 3 | -.246 | .044 | .051 | -.492 | .001 |
| | 5 | -.237 | .049 | .083 | -.511 | .036 |
| 5 | 1 | .083 | .036 | .810 | -.117 | .284 |
| | 2 | .335* | .052 | .031 | .042 | .628 |
| | 3 | -.008 | .060 | 1.000 | -.346 | .329 |
| | 4 | .237 | .049 | .083 | -.036 | .511 |

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Experiment 3, EEG total Beta activity and Colour Env

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | .109* | .013 | .010 | .038 | .180 |
| | 3 | -.059 | .022 | .579 | -.185 | .067 |
| | 4 | .036 | .029 | 1.000 | -.128 | .200 |
| | 5 | -.077 | .029 | .589 | -.241 | .087 |
| 2 | 1 | -.109* | .013 | .010 | -.180 | -.038 |
| | 3 | -.169* | .027 | .033 | -.319 | -.018 |
| | 4 | -.073 | .026 | .460 | -.217 | .070 |
| | 5 | -.186 | .036 | .067 | -.388 | .015 |
| 3 | 1 | .059 | .022 | .579 | -.067 | .185 |
| | 2 | .169* | .027 | .033 | .018 | .319 |
| | 4 | .095 | .027 | .251 | -.057 | .248 |
| | 5 | -.018 | .035 | 1.000 | -.211 | .176 |
| 4 | 1 | -.036 | .029 | 1.000 | -.200 | .128 |
| | 2 | .073 | .026 | .460 | -.070 | .217 |
| | 3 | -.095 | .027 | .251 | -.248 | .057 |
| | 5 | -.113 | .030 | .206 | -.283 | .057 |
| 5 | 1 | .077 | .029 | .589 | -.087 | .241 |
| | 2 | .186 | .036 | .067 | -.015 | .388 |
| | 3 | .018 | .035 | 1.000 | -.176 | .211 |
| | 4 | .113 | .030 | .206 | -.057 | .283 |

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Experiment 3, F3, FZ and F3 Beta activity and Colour Env

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | .106 | .024 | .111 | -.027 | .240 |
| | 3 | -.102* | .011 | .008 | -.165 | -.040 |
| | 4 | .023 | .016 | 1.000 | -.068 | .113 |
| | 5 | -.118 | .036 | .301 | -.318 | .082 |
| 2 | 1 | -.106 | .024 | .111 | -.240 | .027 |
| | 3 | -.209* | .033 | .034 | -.396 | -.021 |
| | 4 | -.084 | .019 | .124 | -.192 | .025 |
| | 5 | -.224* | .039 | .047 | -.445 | -.004 |
| 3 | 1 | .102* | .011 | .008 | .040 | .165 |
| | 2 | .209* | .033 | .034 | .021 | .396 |
| | 4 | .125* | .021 | .041 | .007 | .243 |
| | 5 | -.015 | .042 | 1.000 | -.252 | .221 |
| 4 | 1 | -.023 | .016 | 1.000 | -.113 | .068 |
| | 2 | .084 | .019 | .124 | -.025 | .192 |
| | 3 | -.125* | .021 | .041 | -.243 | -.007 |
| | 5 | -.140 | .039 | .224 | -.358 | .077 |
| 5 | 1 | .118 | .036 | .301 | -.082 | .318 |
| | 2 | .224* | .039 | .047 | .004 | .445 |

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| | 3 | .015 | .042 | 1.000 | -.221 | .252 |
| | 4 | .140 | .039 | .224 | -.077 | .358 |

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Experiment 3, F3, FZ and F3 Alpha activity and Colour Env

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | .211 | .063 | .288 | -.142 | .563 |
| | 3 | -.105 | .033 | .349 | -.292 | .082 |
| | 4 | .077 | .052 | 1.000 | -.216 | .371 |
| | 5 | -.110 | .035 | .339 | -.305 | .085 |
| 2 | 1 | -.211 | .063 | .288 | -.563 | .142 |
| | 3 | -.315 | .083 | .193 | -.782 | .151 |
| | 4 | -.133* | .011 | .003 | -.194 | -.072 |
| | 5 | -.321 | .077 | .140 | -.752 | .110 |
| 3 | 1 | .105 | .033 | .349 | -.082 | .292 |
| | 2 | .315 | .083 | .193 | -.151 | .782 |
| | 4 | .182 | .073 | .667 | -.225 | .590 |
| | 5 | -.006 | .064 | 1.000 | -.362 | .351 |

| (I) ColourEnv | (J) ColourEnv | Mean Difference (I- J) | Std. Error | Sig. ^b | 95% Confidence Interval for Difference ^b | |
|------------------|------------------|---------------------------|---------------|-------------------|--------------------------------------------------------|-------------|
| | | | | | Lower Bound | Upper Bound |
| 4 | 1 | -.077 | .052 | 1.000 | -.371 | .216 |
| | 2 | .133* | .011 | .003 | .072 | .194 |
| | 3 | -.182 | .073 | .667 | -.590 | .225 |
| | 5 | -.188 | .069 | .520 | -.571 | .196 |
| 5 | 1 | .110 | .035 | .339 | -.085 | .305 |
| | 2 | .321 | .077 | .140 | -.110 | .752 |
| | 3 | .006 | .064 | 1.000 | -.351 | .362 |
| | 4 | .188 | .069 | .520 | -.196 | .571 |

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.