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Using neuroscience and behavioural data to tailor visual environments for infants and children

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While there is great public interest in how the design of personal living spaces might affect mental and physical health, to date, there has been little focus on children. Here, we set up a proposal for creating tailored visual environments (TVEs), based on psychological/behavioural and neuroscientific research, to facilitate children's well-being, beneficial moods, and visual development. We begin with a discussion of *infants* during a period when the visual system is developing rapidly (ages 0–3 years), where the main design goal is to create visual interiors that are easily discernible and preferred by infants, with the ultimate goal of facilitating visual development. We then move to a discussion of older *children* (ages 3–17 years), where the main design goal is to use TVEs to counteract 'problematic temperament'. As a first step, we propose that the success of these TVEs be measured behaviourally, asking whether visual perception is enhanced in infants, and whether mood is improved in children, after inhabiting TVEs. As a next step goal, we propose that *neural* and *physiological* measures be obtained in these children as a way of elucidating the biological underpinnings of observed perceptual and behavioural effects.

Keywords: cognitive studies; environment and behaviour; evidence-based design; human behaviour; sensory design

Introduction

The last 30 years have seen an enormous increase in public interest and concern for the effects of environment on health. Over time, this interest has shifted from focusing mainly on the external environment to now include the internal environment of our personal living spaces. The technical scientific literature on the effects of environments on humans has mirrored this historical progression. Early literature focused on external environments and institutional environments such as hospitals, prisons, and shared workspaces. Initially prompted by the work of pioneering Scandinavian researchers in the 1970s (Acking and Kuller 1972), there is renewed interest in how personal living spaces (i.e. visual interiors) might improve well-being, mental health, and mood, with a particular focus on the effects of the *visual environment* (although, the auditory and tactile environment are likely to be important too). However, to date, there has been little (if any) focus on children. Children are particularly important to study because we know from developmental studies that there can be long-term effects of early experiences. In the context of visual experience, it seems critical to consider how visual interiors affect children, who might differ in important ways from adults.

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Here, we set up a proposal for creating tailored visual environments (TVEs), to facilitate children's well-being, beneficial moods, and visual development. We begin with a discussion of *infants* during a period when the visual system is developing rapidly (ages 0–3 years), where the main design goal is to create visual interiors that are easily discernible and preferred by infants, with the ultimate goal of facilitating visual development. We then move to a discussion of older *children* (ages 3–17 years), where the main design goal is to use TVEs to counteract 'problematic temperament'. Our designs for older children are based on the psychological/behavioural literature documenting the effects of different types of visual environment on well-being and mood, in combination with the literature on problematic temperament, which can be measured and may be steered by the environment in beneficial ways.

Before proceeding with an overview of the literature that provides the motivation for the proposed TVEs for children, we make two points. First, although this proposal is grounded in psychological/behavioural and neuroscientific research, to date, clear links between specially designed visual environments and developmental outcomes are yet to be established. The purpose here is to use what is currently known in the literature to develop guidelines for what types of TVEs are likely to be optimal for infants/children, so that these can be implemented and then tested for effectiveness. Second, although the ultimate goal is to understand the effects of TVEs in terms of underlying neural/physiological mechanisms, we strongly believe that assessing behaviour should be the first step, since behavioural studies can inform us about underlying neural mechanisms. As an example, if we know that a child's visual acuity improves as a result of TVEs we can begin to pin down the neural locus of the effect because we know that visual acuity is mediated by low-level stages of visual processing (between the eye and primary visual cortex). Ultimately, the idea is to move in the direction of obtaining direct neural and physiological measures of the observed behavioural effects, so that we may understand the biological underpinnings of any effects of TVEs in a better manner.

Infants (ages 0–3 years)

Effects of early visual experience

Visual scenes possess visual characteristics such as spatial structure, colour, contrast, depth, and motion, which humans and non-human animals have the capacity to detect and discriminate. Many studies have shown that early visual experience has a major effect on development of these visual capacities, seen both at the perceptual level and at the level of visual responses in the brain (see Movshon and Kiorpes 1990 for review), which should be considered when designing TVEs for infants. Specifically, absence of visual input early in development can lead to loss of function or aberrant function (see Lewis and Maurer 2005 for review) and even negative behaviour or poor intellectual function later in life (e.g. Nevskaya, Leushina, and Bondarko 1998). Moreover, studies have shown that visual development is 'instructed' by the visual environment. For example, cats raised in environments that are distorted to present mainly vertical orientations later process vertical orientations better than horizontal orientations (Hirsch and Spinelli 1970). The human analogue to this is referred to as the 'oblique effect'. Humans show greater sensitivity to vertical/horizontal, than oblique (i.e. diagonal), orientations, which is thought to arise because most humans are raised in 'carpentered environments' (buildings, etc.) that contain a preponderance of vertical/horizontals (Switkes, Mayer, and Sloan 1978). As further evidence for this explanation, Cree Indians, who are not raised in carpentered environments and whose Teepees are shaped triangularly, are roughly equally sensitive to all orientations (Annis and Frost 1973).

A final type of evidence showing the effects of visual environment on development comes from studies of the effects of raising animals (typically mice/rats) in enriched vs. impoverished

environments. The results from these studies show that animals raised in cages rich with visual cues show enhanced visual cortical processing and enhanced visual acuity compared with animals raised in impoverished cages (e.g. Cancedda et al. 2004, see Baroncelli et al. 2010 for a review). In humans, the effects of 'added visual experience' have been studied in healthy preterm infants. Here, the notion is that, because they are born early, preterm infants have more time in the world and thus have added visual experience compared with full-term infants of the same adjusted age (i.e. age since due date). As evidence for positive effects of added visual experience, these studies show that healthy preterm infants do, in fact, exhibit accelerated visual development (e.g. Bosworth and Dobkins 2009). In sum, a wealth of data has documented the effects of early visual experience on infant visual development. For this reason, when creating TVEs for infants, it is optimal to present stimuli they can see, as well as stimuli they prefer to look at, which is summarized briefly in the next section.

Infant visual development

What is known about infant vision comes from presenting two-dimensional images on a video monitor, and then using a method called forced-choice preferential looking (FPL) to make inferences about what infants perceive (see Dobkins and Teller 1996). As seen in Figure 1, in the preferential looking method, an infant is held up in front of a video monitor by an adult experimenter. Visual stimuli appear on the monitor, and the adult experimenter judges the looking behaviour of the infant (while not being able to see the stimuli herself). There are two ways the preferential looking paradigm is used. First, it is used to determine what stimuli the infant can *detect*, based on the notion

Figure 1. FPL technique. The adult experimenter holds an infant up to a video monitor containing pictures. Based on the infant's looking behaviours, the adult experimenter can determine which stimuli are detectable to the infant, as well as which pictures the infant prefers to look at.

that infants will preferentially look at a patterned stimulus on one side of a monitor vs. a blank field on the other side. Second, it is used to determine which of two or more stimuli the infant *prefers* to look at. In the sections below, we briefly describe three aspects of infant visual development which are relevant to TVEs: (1) colour vision, (2) spatial vision, and (3) motion processing.

Colour vision

There are two aspects of colour vision that are relevant to TVEs. The first is *colour sensitivity*, which refers to the ability to perceive a pattern based on variations in colour, with the three physiologically defined dimensions of colour vision being black/white, red/green, and blue/yellow (see Dobkins 2000). *Contrast sensitivity,* depicted in Figure 2, refers to the amount of contrast (difference) between two colours required for an individual to detect the presence of a pattern. In the first year of life, infants have relatively poor contrast sensitivity for all three dimensions of colour, which means they need high contrast in order to see a pattern clearly (e.g. Dobkins, Anderson, and Kelly 2001). The other aspect of infant colour vision which is relevant to TVEs is colour *preference.* Using preferential looking, several studies have shown that infants prefer reds and blues over greens, yellows, and whites (e.g. Teller, Civan, and Bronson-Castain 2004).

Spatial vision

There are several aspects of spatial vision which are relevant to TVEs. The first is *acuity*, which refers to the ability to resolve very fine details in an image. Acuity is poor in infancy (Aslin and Smith 1988), due to infant photoreceptors (light-detecting cells in the eyes) being more sparsely placed than those of adults (Hendrickson and Yuodelis 1984). It is not due to poor optics (Banks and Crowell 1993), which, were it the case, could be fixed with corrective lenses. Owing to their low acuity, infants can see patterns with coarse, but not fine, texture. The degree of coarseness is quantified by a term known as 'spatial frequency' (see Figure 3), which is defined as the number

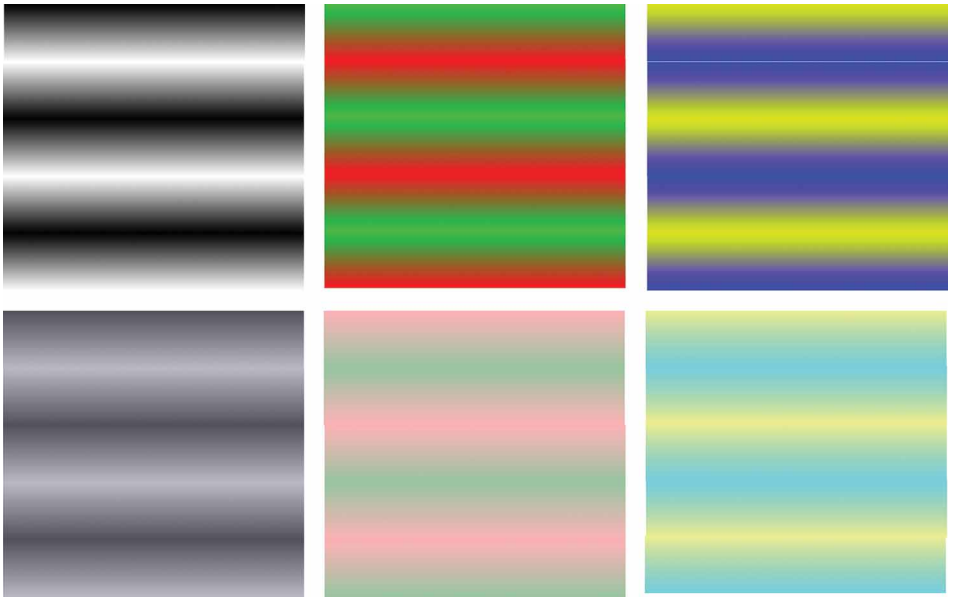

Figure 2. Low and high contrasts of white/black, red/green, and blue/yellow patterns.

of cycles of colour variations in a grating (e.g. from black to white, or from red to green, etc.), across space with space defined in terms of visual angle. A coarse pattern (Figure 3, *left*) will have a low spatial frequency (e.g. 0.1 cycle/degree). A fine pattern (Figure 3, *right*) will have a high spatial frequency (e.g. 20 cycles/degree). Adults can resolve up to 55 cycles/degree, and their peak sensitivity is at about 3 cycles/degree for black/white and about 0.1–1 cycles/degree for red/green and blue/yellow. For infants in the first year of life, the peak is at about 1 cycle/degree for black/white and 0.5 cycle/degree for red/green and blue/yellow (Peterzell, Chang, and Teller 2000).

Other aspects of spatial vision which are relevant to TVEs are *orientation*, *gestalt processing*, *and symmetry.* With respect to *orientation*, depicted in Figure 4, newborn infants have poor orientation discrimination, at best, being able to discriminate a 45° difference, and this ability improves over the first year of life (Atkinson et al. 1988). Infants have highest sensitivity to horizontal and vertical orientations (Birch et al. 1983) and prefer to look at verticals (Bornstein 1982). With respect to *gestalt* processing (i.e. seeing the whole from the parts), infants gradually go from preferring simple to complex patterns (Strauss and Curtis 1981), and from preferring the parts of an object to the whole (Quinn and Bhatt 2009). With respect to *symmetry*, depicted in Figure 5, infants go from being able to discern vertical symmetry, then horizontal symmetry, and then diagonal asymmetry (Bornstein, Ferdinandsen, and Gross 1981), and they prefer to look at vertical + horizontal symmetry the most (Humphrey et al. 1986).

A final aspect of spatial vision which is relevant to TVEs is *face processing*. Not surprisingly, given the importance of face identification, newborn infants exhibit looking preferences to faces

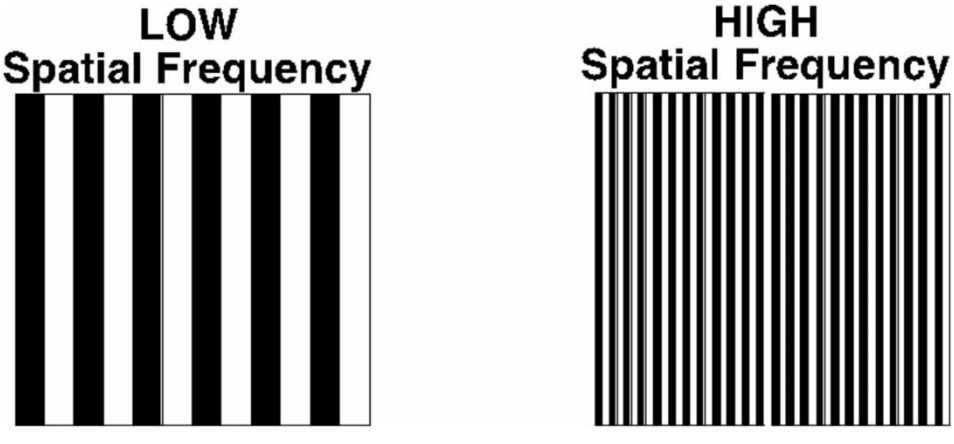

Figure 3. Spatial frequency. The left pattern shows low spatial frequency variation in black/white, the pattern is coarse. The right pattern shows high spatial frequency variation, the pattern is fine.

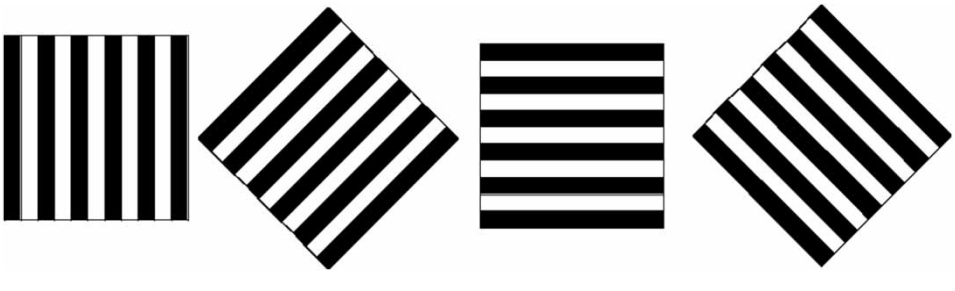

Figure 4. Orientation. Four patterns each differing by 45° orientation from one to the next.

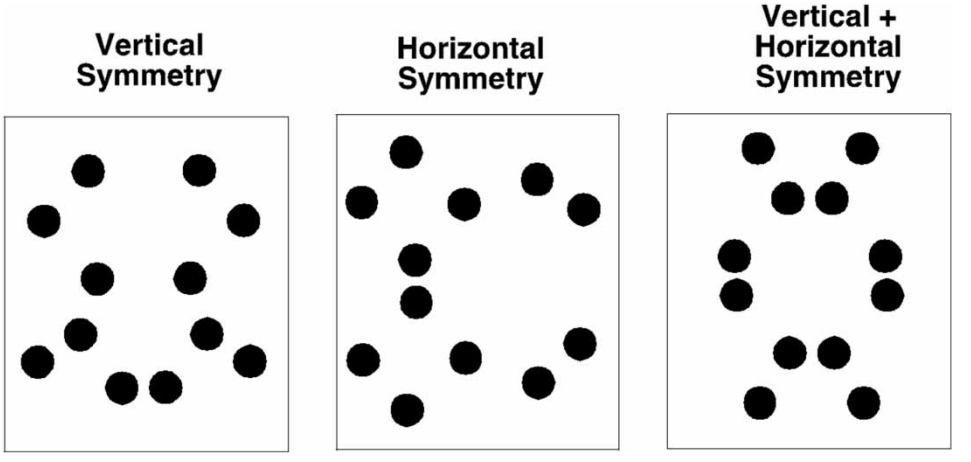

Figure 5. Symmetry. Examples of patterns exhibiting vertical symmetry, horizontal symmetry, and both.

over almost any other kind of stimulus (Goren, Sarty, and Wu 1975; Jirari 1970), and this preference continues to develop throughout infancy (Haaf 1977; Maurer and Barrera 1981). Infants also show specific preferences for certain aspects of faces, preferring to concentrate on eyes (Farzin, Rivera, and Hessl 2009). Infants also prefer smiling vs. non-smiling faces (Kuchuk, Vibbert, and Bornstein 1986).

Motion processing

The last aspect of vision which is particularly relevant to TVEs is motion processing. Like faces, an early ability to detect motion is particularly important, allowing infants to avoid being hit by moving objects. As might be expected, then, sensitivity to motion develops very early (e.g. Dobkins and Teller 1996). In terms of preferences, infants prefer moving stimuli to static stimuli (Volkmann and Dobson 1976), which is why mobiles are so popular.

Designing TVEs for infants (ages 0–3 years)

Because research shows that deprivation negatively affects visual sensitivity and that enriched environments enhance visual processing (see above), we assume that the more an infant is exposed to visual stimuli, the more their visual development will be facilitated. Accordingly, TVEs are designed to increase infants' exposure to visual stimuli in two ways: (1) by presenting stimuli that we know are *visible* to infants (based on detectability studies), and (2) by presenting stimuli infants are likely to want to look at (based on preference studies), as outlined above.

(1) Colour
   - Use high contrast patterns.
   - Emphasize reds and blues.

(2) Spatial patterns
   - Pattern coarseness: use large patterns. To specifically accommodate infants in the first year of life, the spatial frequency should be less than 1 cycle/degree for a black/white pattern, and less than 0.5 cycle/degree for red/green or blue/yellow patterns. The actual

size of these patterns, in terms of centimetres, needs to be determined based on the bedroom size, and maximal viewing distances.
- Orientation: emphasize *vertical* orientations in bedroom design.
- Simplicity vs. complexity: Because only the youngest infants (i.e. less than 4 months) prefer simple over complex stimuli, the bedroom patterns can be fairly complex. However, the patterns should be fairly regular.
- Symmetry: use symmetrical patterns, with the largest emphasis on *vertical* symmetry.
- Faces: use pictures of faces. These faces can be schematic, but more realistic faces are best. The eyes of the face are most important.

(3) Motion
- Use an infant mobile. We recommend one that is black, white, red and blue, moves and plays music. All these features are highly visible and infants prefer to look at them.

When considering visual environments for infants (ages 0–3 years), we focused on features that would be detected and preferred, with the goal of stimulating the visual system. We focused on ages 0–3 years because visual development is largely complete by age 3 years. In considering visual environments of *older* children, we propose that visual environments should be designed to complement children's temperaments in ways that might benefit their social and emotional development. We focus on ages 3–17 years because temperament is thought to be stable by 3 years; once they are stable they can be targeted in different ways, as discussed in the next section.

Children (ages 3–17 years)

Temperament in children

The term *temperament* refers to behavioural consistencies that are frequently (but not exclusively) emotional in nature and have a presumed neurobiological basis. Temperament is thought to be relatively stable past about 3 years of age (Lemery et al. 1999). Several different classification schemes for temperament have been developed with a fair degree of overlap across them (see Shiner et al. 2012; Zentner and Bates 2008 for reviews). According to Rothbart et al. (2001), there are 15 dimensions of temperament: activity level, anger/frustration, approach, attentional focusing, discomfort to pain, soothability, fear, high intensity pleasure, impulsivity, inhibitory control, low intensity pleasure, sadness, shyness, and perceptual sensitivity. Of these 15 dimensions, there are 4 that we feel can most directly be complemented with a TVE that might 'balance out' a problematic temperament. These are (1) Shyness, (2) Anger, (3) Sadness, and (4) Perceptual Sensitivity (which refers to being adversely affected by stimuli, for example, avoiding bright lights and/or visual clutter). It is worth pointing out that the dimension of *shyness*, which is relevant to the topic of TVEs for children (*see below*), is actually thought to be an indicator of *arousal levels*. The notion is that children who are very shy exhibit high levels of arousal in response to novel situations, and thus they withdraw from this 'overstimulation'. These children tend to have high levels of physiological arousal associated with the sympathetic branch of the autonomic nervous system, as measured by a wide range of indices including high concentrations of stress hormone (cortisol), enhanced pupillary dilation, and high levels of heart rate variability (e.g. Kagan et al. 1994).

Long-term effects of 'problematic temperament' profiles

Temperament is considered to be especially important in childhood because problems in temperament, which we henceforth refer to as 'problematic temperament', have been associated with adverse outcomes later in life (see Rothbart, Ahadi, and Evans 2000; Shiner 1998 for reviews). To give some examples, children who are high in activity level (e.g. not able to sit still) have a

greater chance of social adjustment problems later in life (Fogal 1991). Children who have high levels of shyness early in life, later on have a greater risk for: (1) internalization of problems (with anxiety and negative feelings about the self) and poor concentration (Eisenberg et al. 2000), (2) being depressed, impulsive, and antisocial (Caspi 2000), and (3) having anxiety disorders (Kagan and Snidman 1999). High levels of negativity early in development are also associated with being aggressive (Rothbart, Ahadi, and Evans 2000), negative, distractible, and impulsive (Caspi 2000) later in life.

Interactions between temperament and the environment: goodness-of-fit

There is evidence that a child's long-term social adjustment results from an interaction between the child's temperament and environment. This is known as goodness-of-fit (see Goodnight et al. 2008; Lerner et al. 1989), which is discussed in the reviews cited above. As might be expected, the environment can interact with temperament in either a beneficial or detrimental fashion, and this effect may be amplified for children whose temperament is extremely negative (Belsky, Bakermans-Kranenburg, and van Ijzendoorn 2007). For example, few parents are aware that shy children tend to feel over-stimulated, and often make the mistake of responding to these children by further stimulating them, which can lead the child to withdraw more (Fogal 1991). Accordingly, if the intensity of stimulation is reduced for shy children with high levels of arousal it may reduce the long-term adverse effects that are often seen in these children (Fogal 1991). In sum, it is important to deal with problematic temperament early in life in order to prevent more serious behavioural problems later on (see Chess and Thomas 1989). Thus, the goal for TVEs is to first determine which children exhibit problematic temperaments, and then to recommend bedrooms that counteract these children's problematic temperament, with the aim of optimizing well-being and increasing the overall chance for a positive outcome.

Measuring temperament

There are a variety of ways in which temperament can be measured, including parent questionnaires, home observations, and laboratory observations (see Kagan et al. 1994 for a review). We recommend use of parent questionnaires, followed by parent interview, because parents are likely to have a wide range of experiences on which to base their judgements, and this method is simple, direct, and inexpensive to use. Parents read through a list of 48 total questions, and answer on a scale from 1 (not at all true) to 7 (very true). The questions cover four domains of problematic temperament: (1) Shyness (13 questions), (2) Anger (13 questions), (3) Sadness (13 questions), and (4) Perceptual Sensitivity (9 questions), taken from sections of the 'Child Behavioral Questionnaire' of Rothbart, Ahadi, and Evans (2001), and the 'Sensory Profile' of Dunn (1994). The goal is to catch children who score *high* on any of the four domains (i.e. who have a 'problematic temperament'). Although there is no universally accepted demarcation of what is considered 'problematic', we recommend a starting definition of 1 standard deviation (SD) *above* the mean. To determine which scores correspond to 1 SD above the mean, one needs to obtain normative data, preferably with the relevant demographics (e.g. location, socio-economic status, ages: 3–5 years, 6–8 years, etc.). This creates a frequency distribution, with a mean (i.e. average) and SD (a measure of variability). Again, as a starting point, children who are greater than 1 SD above the mean (which is roughly the top 17%) will be classified as having a 'problematic temperament'. In all cases, as a next step, the results of the questionnaire would be discussed with parents in informal interviews, in order to get their input. Parent opinions during the interview may differ from the questionnaire results. Working together with parents and the results from the questionnaire, a decision would be made about which bedroom type might best complement the child. The bedroom types we

recommend promote moods like tranquillity, positivity, and engagement. To promote those moods, we turn next to studies which have investigated the effects of visual scenes on mood.

The effects of visual scene on mood

Among lay people, perhaps the most commonly talked about link between visual environment and mood is in the domain of *colour*, that is, across cultures, there is a popular belief that colours possess qualities that affect mood (see Beach, Wise, and Wise 1988 for a review). To begin, one can simply ask what colours people prefer. In the earliest study of this question, which tested more than 21,000 people, the order of colour preference (from most to least) was reported to be: (1) blue, (2) red, (3) green, (4) violet, (5) orange, and (6) yellow (Eysenck 1941). Studies have also shown that saturated colours are preferred over unsaturated colours (Beach, Wise, and Wise 1988; Guilford and Smith 1959, but see Helson and Lansford 1970; Kwallek et al. 1996 for a more complex view).

In terms of the link between *colour* and *mood*, the scientific literature is small and growing, with a general consensus that adding colour improves well-being. For example, in a study conducted in the workplace, the highest reports of well-being were found in colourful work places (Kuller et al. 2006). Another study showed that adding colour to black and white pictures leads to overall improvement in well-being of the viewer (Saito and Tada 2007). In addition, *saturated* colours are rated as evoking more dynamism and activity (Hogg et al. 1979). In terms of the *specific* quality of mood promoted by different colours, it is generally agreed upon that colours at the shorter wavelength end of the spectrum (blues and greens) are 'calming' and 'tranquillizing', whereas colours at the longer wavelength end of the spectrum (oranges and reds) are 'arousing', 'stimulating', and 'exciting'. These relationships have been found when rating: small pieces of coloured paper (e.g. Hogg et al. 1979; Wexner 1954), marketing logos in different colours (Labrecque and Milne 2012), pictures of room interiors (e.g. Yildirim, Hidayetoglu and Capanoglu 2011), and real room interiors (when the rater is sitting in the room and rating perceived comfort and arousal, e.g. Acking and Kuller 1972; Walters, Apter, and Svebak 1982). In addition to properties like 'calming' and 'stimulating', other studies have asked people to judge the positivity of colours. In one of the earliest studies, yellow was rated as the most 'cheerful' and 'positive' colour (Wexner 1954). In a more recent study (Kaya and Epps 2004), it was found that college students rank the primary colours (red, yellow, green, blue, and purple) as most positive, followed by intermediate colours (yellow-red, blue-green, purple-blue, and red-purple, although green-yellow is rated particularly low since it is associated with vomit), and lastly achromatic colours (grey and black, although 'white' is often rated positively). Relatively few studies have tested children. In one, results show that 5- to 6-year-old children judge bright colours (e.g. pink, blue, and red) as positive and dark colours (e.g. brown, black, and gray) as negative (Boyatzis and Varghese 1994), in general alignment with what adults report.

Brightness, which is another dimension of colour vision, has also been studied. Bright walls are rated as making rooms appear more spacious, and perceived spaciousness is also increased by the use of low contrast images on the walls (Beach, Wise, and Wise 1988). This latter effect arises because contrast is a cue for depth perception: atmospheric haze reduces the contrast of distant features (e.g. Gregory 1970). This means that the visual system may be 'tricked' into believing that objects are further away when they are lower in contrast, and this can be used to increase the perceived spaciousness of room interiors. In addition, brightly lit interior spaces are rated as more cheerful (Beach, Wise, and Wise 1988), although rooms that are too bright are deemed undesirable (Kuller et al. 2006).

Outside the domain of colour, another aspect of visual scenes that has been studied is *naturalistic* features. It is generally believed that there are therapeutic effects of viewing naturalistic or

artistic scenes (see Lankston et al. 2010 for a review). For example, hospital patients heal faster if they can see natural green scenes from their windows (Ulrich 1993). Research has focused on making interior living spaces contain features that suggest a connection to the naturalistic external world (e.g. that contain artwork of landscapes, projected images of tree canopies and foliage, symbols of water, e.g. Clay 2001; Wise 1997). Results suggest that viewing natural settings can improve mood (Saito and Tada 2007) and focused attention (Berman, Jonides, and Kaplan 2008) and may reduce the incidence of attention deficit hyperactivity disorder behaviour in children (see Clay 2001). Together, research suggests that naturalistic features may promote calmness and tranquillity.

Designing TVEs for children (3–17 years)

We focus on ages 3–17 years because temperament is stable starting at about 3 years (see above) and 17 years is typically the final year of 'childhood', after which individuals act independently of their parents. Future research could be focused on fine-tuning the needs of different ages *between* 3 and 17 years. Based on the research reviewed above, the design challenge is to assess a given child's temperament and then recommend a TVE that promotes certain psychological states (moods) that best complement that child's particular temperament. More specifically, as a starting point, we propose that bedroom recommendations be made for those children with a 'problematic temperament' (i.e. within the top 17% on a given problematic temperament domain), with the idea of steering those children towards a better developmental outcome. As described above, temperament is assessed with a Parent Questionnaire, with four domains: Shyness, Anger, Sadness, and Perceptual Sensitivity (see Appendix 1). Because Anger and Sadness are both types of negativity, both being predictive of the same sorts of adverse outcomes, and both thought to be ameliorated with the same sort of positive input, we put them together as a single temperament category called 'Negative Affect'. As such, the three final domains of temperament, which are deemed to be problematic if the child scores extremely high on them, are divided into:

(1) Shyness,
(2) Negative Affect (either Anger or Sadness),
(3) Perceptual Sensitivity.

Based on the assessment of the child (from the questionnaire and interview with parents), we will recommend a particular bedroom type and/or accommodations (described below). The first two domains of temperaments (1 – shyness and 2 – negative affect) will be used to determine the bedroom type recommendation, and once that has been determined, the other aspect of temperament (3 – perceptual sensitivity) will be used to determine whether additional accommodations are recommended.

Temperament	Recommendations
Child scores high on 1 ->	Tranquillity bedroom (TB)
Child scores high on 2 ->	Positivity bedroom (PB)
Child scores high on 1 and 2 ->	Tranquillity + positivity bedroom (TPB)
Child does not score high on either 1 or 2 ->	Engagement bedroom (EB)
Child scores high on 3 ->	Recommended bedroom plus reduce clutter (RC)

As a starting point, these rooms have the following design features:

TB: Use cool colours (i.e. blues and greens) and pictures of natural scenes (e.g. available as wall paper or painted murals).

PB: Use bright and saturated colours, and several different colours combined, and include happy faces.

TPB: Use combined properties from TB and PB.

EB: Use warm, stimulating colours (i.e. reds and oranges), saturated colours, and stimulating designs (painted accentuations across the walls, or wall paper with designs).

RC: Promote good use of drawer space to minimize clutter, and dimmer switch lights or lamps to reduce light level, use lower contrast features to promote spaciousness.

*On a final note, given that the child is old enough, we suggest parents work alongside their children, using their favourite colours whenever possible.

Conclusions

We propose that TVEs may address several design challenges for infants and children. For infants, whose visual system is developing rapidly, the design challenge is to help facilitate basic visual development in infants. This can be achieved by creating visual interiors that are easily discernible and preferred by infants. For children, the challenge is to promote certain psychological states (moods) that best complement an individual child's particular temperament. This can be done by working with parents to assess temperament, in particular, catching children with 'problematic temperaments', exposing them to visual scenes that promote a more positive and/or tranquil mood, with the ultimate goal of steering them towards a better long-term outcome. However, it should be noted that, unlike the literature for adults, for *children*, there is very little known about the effects of visual scenes on mood and well-being. Thus, as a first step, it would be advisable to conduct more well-controlled and systematic laboratory studies in children to determine the effects of different visual scenes on mood. In addition, future research should include the effects of other sensory modalities (auditory sounds, tactile surfaces, and odours) on moods. Once this has been accomplished, the exact specifications of TVEs for children can be optimized.

The next step is to measure, first behaviourally, the success of TVEs after infants/children have inhabited them for a while. For *infants*, this would entail measuring functions like *visual contrast sensitivity* before vs. after living in TVEs, to see if age-related increases in sensitivity are greater than those seen in infants not living in TVEs. For *children*, this would entail measuring temperament and well-being, to see if there are overall shifts and/or improvements as a result of living in TVEs. Note that in the current design model, we categorize children in the same way regardless of whether they score high on Anger or Sadness. We chose to do so because both emotions are predictive of similar adverse outcomes, and children who display either one are thought to benefit from the same types of input. However, empirical research is needed to verify that collapsing across these types of negativity is warranted. In a similar vein, empirical research is needed to look at the effects of TVEs at different ages between 3 and 17 years (e.g. preschool, elementary, middle school, and high school years). In addition, although we are not making claims that *intelligence* should be affected by TVEs, it will nonetheless be of interest to use standard IQ measures before vs. after living in TVEs, to determine whether this capacity is affected.

Ultimately, the idea is to move in the direction of obtaining *neural* and *physiological* measures of the observed behavioural effects, so that we may understand the biological underpinnings of TVEs in a better manner. For infants/children, the most feasible neuroscientific method would be the use of electroencephalography, where latencies and amplitudes of brain responses to different TVEs could be measured with an electrode cap placed on the infant's head. This neural measure, in coordination with measures of physiological arousal (stress hormone levels, pupillary

dilation, and heart rate variability) has the potential to shed light on the effects that personal living spaces have on neural and physiological processing in infants and children.

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Appendix 1: Temperament questionnaire for parents

These 47 questions are taken from sections of the 'Child Behavioral Questionnaire' of Rothbart, Ahadi, and Evans (2001), and the 'Sensory Profile' of Dunn (1994). Parents rate each statement on a scale from 1 (untrue) to 7 (very true). For each dimension of temperament assessed (Shyness, Anger, Sadness, and Perceptual Sensitivity), a score is computed which is the average across questions for that dimension. Items designated by 'R' are reverse-scored (i.e. they are re-coded so that 1 becomes 7, 2 becomes 6, 3 becomes 5, 4 remains 4, 5 becomes 3, 6 becomes 2, and 7 becomes 1). Items denoted by 'SP' are taken from Dunn (1994), sensory profile. Means for each dimension are expected to be around 4.

Note that on the actual form, the parent does not see the labels for different dimensions of temperament, and the questions are in random order. The 'R' is also not shown to parents.

Shyness

My child...
1. Sometimes prefers to watch rather than join other children playing.
2R. Is comfortable in situations where s/he will be meeting others.
3R. Seems to be at ease with almost any person.
4. Gets embarrassed when strangers pay a lot of attention to her/him.
5R. Acts very friendly and outgoing with new children.
6R. Joins others quickly and comfortably, even when they are strangers.
7. Is sometimes shy even around people s/he has known a long time.

8. Sometimes seems nervous when talking to adults s/he has just met.
9. Acts shy around new people.
10R. Is comfortable asking other children to play.
11R. Talks easily to new people.
12. Sometimes turns away shyly from new acquaintances.
13R. Seems completely at ease with almost any group.

Anger

My child...
1 Gets angry when told s/he has to go to bed.
2R. Rarely gets irritated when s/he makes a mistake.
3. Has temper tantrums when s/he doesn't get what s/he wants.
4. Gets quite frustrated when prevented from doing something s/he wants to do.
5. Gets mad when even mildly criticized.
6. Gets angry when s/he can't find something s/he wants to play with.
7R. Rarely gets upset when told s/he has to go to bed.
8. Becomes easily frustrated when tired.
9. Gets irritable about having to eat food s/he doesn't like.
10R. Rarely protests when another child takes his/her toy away.
11. Easily gets irritated when s/he has trouble with some task (e.g. building, drawing, and dressing).
12. Gets angry when called in from play before s/he is ready to quit.
13. Gets mad when provoked by other children.

Sadness

My child...
1. Cries sadly when a favourite toy gets lost or broken.
2. Tends to feel 'down' at the end of an exciting day.
3. Tends to become sad if the family's plans don't work out.
4. Seems to feel depressed when unable to accomplish some task.
5. Becomes upset when loved relatives or friends are getting ready to leave following a visit.
6R. Does not usually become tearful when tired.
7. Her/his feelings are easily hurt by what parents say.
8. Becomes sad when told to do something s/he does not want to do.
9R. Rarely cries when s/he hears a sad story.
10R. Rarely becomes upset when watching a sad event in a TV show.
11. Sometimes appears downcast for no reason.
12R. Rarely becomes discouraged when s/he has trouble making something work.
13. Seems to feel sorry for her/himself when things are going badly.

Perceptual sensitivity

My child...
SP1: Prefers to be in the dark.
SP2: Expresses discomfort with or avoids bright lights (e.g. hides from sunlight through car window).
SP3: Happy to be in the dark.
SP4: Becomes frustrated when trying to find objects in competing background (like a cluttered drawer).
SP5: Has difficulty putting puzzles together (as compared with other children his/her age).
SP6: Is bothered by bright lights after others have adapted to the light.
SP7: Covers eyes or squints to protect eyes from light.
SP8R: Looks carefully or intensely at objects/people (e.g. stares).
SP9: Has a hard time finding objects in competing backgrounds (e.g. shoes in a messy room, favourite toy in the junk drawer).