RESEARCH ARTICLE

The potential of positive places: Senses, brain and spaces

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There is an enormous amount of intricate research available on specific aspects of building performance in relation to users. However, there is currently no framework for designers to bring together these diverse findings. As a result, a significant opportunity is being missed to support radically more positive outcomes for the occupants of buildings. To help address this gap, this article proposes a framework that captures the essence of an individual's holistic experience of spaces, created by the combined impacts received through their senses and mediated by their brain. The early sections illustrate the complex and dynamic ways in which humans receive information about their surroundings through their senses, with profound, but fragile and interactive effects on human health, mood and performance. This is strategically framed using neuroscience theories about the way the human brain makes calculations to link perceptions to actions. This leads to the proposition that design should take into account issues of naturalness, individualization and level of stimulation. It is further suggested that a multidisciplinary, multi-level research approach is needed to support the creation of spaces that provide people with sensory environments that help them reach, or sustain, their fullest possible potential.

Keywords: brain; design; human performance; neuroscience; senses; spaces; value

INTRODUCTION AND BACKGROUND

People spend a high proportion of their lives indoors, indeed this has been estimated to be as high as 90 per cent (CIB Task Group 42, 2004). Thus, the potential impact of the quality of spaces on health and well-being is great. Unfortunately, it appears that individuals are often not satisfied with even the basic conditions of their living environments, such as temperature, lighting and air quality, with a number of consequential negative health effects (Bonnefoy et al., 2004; World Health Organization, 2007).

Currently, legislation and guidelines are used predominantly to define thresholds for discrete environmental factors: air quality (ventilation), thermal, acoustic and visual factors. Once basic standards have been met there is often no clear guide to priorities, and evaluating the effects of the physical environment in relation to multiple factors is difficult owing to the interplay of factors (Higgins et al., 2005, p36). So just because an indoor built environment is meeting current standards for environmental factors, it may not necessarily mean that a

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building is healthy, comfortable and safe from the users' and occupants' perspective. For example, most standards, such as for thermal comfort, are based on averaged data thereby overlooking the fact that buildings, individuals and their activities may differ widely. However, there is increasing awareness of the need to understand the particular needs of users (Saxon, 2006, p30) and the way they actually use their building, which may itself influence conditions (Bonnefoy et al., 2004, p17). The complexity of these technical issues calls for an approach that aims to look beyond base threshold levels, to develop holistic, integrated solutions from users' perspectives.

In going beyond the issue of avoiding 'bad' spaces, there is the question of how much *good* space could contribute to society in terms of optimal human functioning. This logically lies at the heart of the assessment of the value of the built environment in society and should drive 'an awareness of the systemic contribution' that buildings (Barrett, 2008), and more specifically spaces, make to our lives. To better understand the impact of spaces on humans, this article takes the stance that this experience happens via our senses, with the human subject then combining the inputs in their brain and coming to a holistic, individual response.

Thus, how we 'sense' our environment is key. The next section focuses on this, including some selected examples of the evidence about the tangible impacts of different sense experiences on human functioning. Then follows a section drawing from basic neuroscience theories as to how we make calculations using sense inputs and how we achieve a holistic perception of space. From this, a section on design implications leads into conclusions about the potential and challenges of this research area.

SENSE PERCEPTION AND HUMAN RESPONSE

This section sets out to provide some illustrations of the complex dynamics of the various sense impressions people experience in spaces. Two themes are pursued throughout: first, the non-linear and relative nature of individuals' impressions; and, second, the powerful impacts on human health and functioning. Finally, some complicating issues will be raised, including interactive effects between the various sense experiences, both physiologically and socially driven. Examples will be given concerning colour, lighting, layout, air quality and acoustics. In each case, general material is included twinned with examples drawn from the relatively controlled environment of schools where there are available some explicit measures of human performance, such as exam/test results.

COLOUR

Central to the impact of colour is the curvilinear issue of avoiding over- or under-stimulation through the degree of complexity or unity (uniformity) employed (Mahnke, 1996, pp22–27). There are many examples of the importance of difference and balance, rather than absolute colours, mediated to some extent by natural expectations, e.g. dark below and light above (Durao, 2000). In addition, laboratory experiments have shown that different colours can directly affect an individual's impression of, for example (Mahnke, 1996, pp72–75):

- temperature – light blue cooler; red/orange warmer;
- sounds – shrill, high pitched may be offset by olive green;
- size of objects – dark colours heavier; less saturated colours less dense;
- size of spaces – light or pale colours recede and so increase perception of size; dark or saturated hues protrude and decrease apparent size.

When selecting colours, the nature of the task is relevant. When concentration is sought, it can be assisted through the use of different colours, discriminating between those that are psychologically stimulating as opposed to physiologically stimulating. For example, in schools, cooler hues have been found to be good for concentration (Mahnke, 1996). Other studies have shown that intensity of colour, unity of colour schemes (Durao, 2000, p100) and contrasting end wall colour (Nuhfer, 1994) are also influential. Considering personal preferences, Heinrich (1980, 1992) carried out psychological colour tests on 10,000 children in age bands from 5 to 19 years and found, for each band, their preferred colours for their school environment. However, Heinrich points out that these colours are not always suitable for direct translation into wall colours.

LIGHTING

It is argued that natural daylight has a greater probability of maximizing visual performance compared with electric light because it tends to be delivered in large amounts, with a spectrum that ensures excellent colour rendering (Boyce et al., 2003, p65). Evidence from research on the impact of design in hospitals shows outcomes related to the variables of nature and light. Studies in a Swedish hospital on heart surgery patients showed the viewing of nature reduced patients' stress and need for analgesia compared with those in control groups (Ulrich, 1991; Ulrich et al., 2004). However, Boyce et al. (2003) argue that the 'biophilia hypothesis' ought to be investigated to better understand the role of windows and the relative impact of a view out versus letting daylight in (p68). Whatever the scenario, they maintain that the effectiveness of daylighting (and artificial lighting) will depend on how it is delivered (p65), linking to issues of glare and distraction. From an occupant's perspective, there is often a battle between the desire to be close to a window versus the problem of glare (Christoffersen et al., 2000).

When day lighting is not available, preferred lighting levels have been shown to be higher than indoor lighting standards and may correspond to levels where biological stimulation can occur (Begemann et al., 1996). Special artificial lighting that emulates the full spectrum of sunlight can be used to tap into natural circadian rhythms with powerful impacts on involuntary emotions (Rea et al., 2002; Joseph, 2006). For example, Figueiro et al. (2003) have drawn on the physical fact that blue light has the maximal effect on circadian rhythms to work with Alzheimer's patients to improve their sleeping patterns through exposure to quite low levels (300 lux) of blue light for two hours before the patients' normal time for going to sleep. It was found that this level of exposure shifted the patients' level of activity towards the day and away from the night, delaying the decline of body temperatures by two hours and leading to enhanced sleeping between 2.00 am and 4.00 am.

Looking more specifically at schools, the Heschong Mahone Group (1999) studied the impact of daylighting on learning in schools. They looked at 21,000 elementary school pupils and classified 2000 classrooms for their daylighting levels. Controlling all other influences and using multiple linear regression analysis, they found positive correlations between the variables: that students with the most daylight progressed 20 per cent faster in mathematics and 26 per cent faster in reading compared with those with the least. However, this finding was reversed when there was glare from certain designs of skylight. Furthermore, another study by the same group in 2003 (Heschong Mahone Group, 2003), of different schools in a different climate, found daylight was not significant in predicting performance. Further analysis showed that other characteristics associated with daylighting, which did not exist in the earlier studies, such as noise, were affecting performance through a counteracting negative effect. This highlights both the strength of the potential impacts and their fragility, especially in combination with other factors.

LAYOUT

Issues of layout have been shown to affect behaviour; for example, aggression and destructive behaviour increase as the size of the classroom and number of children in it increases (Rivlin and Wolfe, 1972). High-density situations (too many children or too little space) lead to excess levels of stimulation, stress and arousal, reductions in desired privacy levels and loss of control (Wohlwill and van Vliet, 1985). Academic performance suffers (Achilles et al., 1998) as students' sense of responsibility and meaningful participation is discouraged (Moore and Lackney, 1994). Within this context, Marx et al. (1999) found that semi-circular seating arrangements engendered a significantly higher, and enduring, level of question-asking in fourth graders compared with row-and-column arrangements.

Clearly marked pathways through the building and within classrooms improve the utilization of spaces, but more importantly they help keep the children orientated and stimulate their imaginations (Alexander, 1977). More tangibly, school buildings and grounds with 'clearly defined areas for freedom and movement' have been found to correlate significantly with higher student ITBS (Iowa test for basic skills) scores (Tanner, 2000, p326). Indeed, student activities in naturally planted 'school yards' have been shown to be more creative than in classrooms or traditional playgrounds (Lindholm, 1995), with positive effects on learning and cognitive qualities (Fjortoft and Sageie, 1999; Fjortoft, 2004). As an example of interaction between navigation and colour, it has been found that the use of colour to assist way-finding is especially important in primary schools (Engelbrecht, 2003).

AIR QUALITY

Perceptions of air quality are not absolute. There are varying decay curves for the perception of different smells depending on their source. For example, in laboratory conditions, adaptation to natural human body smells is quicker than to tobacco or building smells (Gunnarsen and Santos, 1999). However, *perceived* air quality cannot be the only measure for health effects as some toxic pollutants, such as carbon monoxide and radon, are not perceived (Berglund et al., 1999).

A study of a primary school class by Coley and Greeves (2004) investigated the effects of low ventilation rates on their cognitive functions. The research used a range of computerized tests and showed that the attentional processes of the children were significantly slower, by approximately 5 per cent, when the level of carbon dioxide (CO_2) in the classroom was high. Other studies have found a statistically significant association with CO_2 levels and absence levels from school. However, this is thought to be an indicator of low ventilation rates leading to increases in communicable respiratory illnesses (Fisk, 2000).

ACOUSTICS

The multidimensional acoustical experience in, for example, performance spaces, exhibits two interesting tensions. One is experienced by the audience, between clarity and reverberance, which tend to act against each other (Hidaka and Nishihara, 2004). The second tension is between desirable listening conditions for performers and audience. Performers need to feel 'support' from the hall, and so would like the most information-rich sound reflections returned quickly to the stage, while the audience wants all this important energy directed towards them (Jeon and Barron, 2005).

Evans and Lepore (1993) have isolated the negative effect of noise on children's recall. They studied 1358 children aged 12–14 years in their own classrooms, using standard tests, but under different noise conditions. They then tested the pupils' recall a week later and found that a statistically significant decline in performance could be associated with the noisy conditions. This negative effect has also been shown to affect long-term recall in children (Hygge, 2003).

COMPLEXITY AND INTERACTION

The individual's sense experiences clearly tend to be relative and changing. But it can be seen that they are also interactive. Santos and Gunnarsen (1999) have specifically studied this phenomenon for an individual's choice between the noise of air conditioning (in a hot country) against being too hot. By working with subjects they mapped 'iso-annoyance curves' that represent where people trade between these alternatives, see Figure 1.

The human environmental sensory experience is further complicated by changes in a person's sense organs over time. For example, the aging

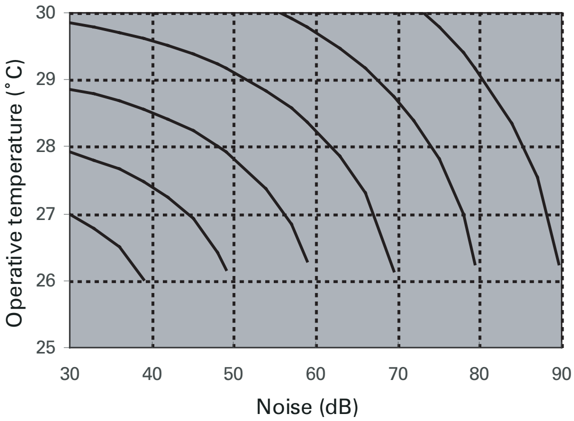

FIGURE 1 Example iso-annoyance curves

of eye lenses requires higher light levels to function well (Joseph, 2006), which makes colour discrimination more difficult (Durao, 2000, p113). Furthermore, the problem of glare intensifies (European Commission, 2003). In addition, the capacity and qualities of the brain varies over a lifetime (Carter, 1998, p21), with changes through potentiation or pruning of connections occurring through learning (Goswami, 2004). For example, the capacity of a child's brain shows less flexibility than an adult's in processing changes in spatial categories (Hund and Plumert, 2004), but the elderly (Sundstrom et al., 1996) and those with Alzheimer's disease also have problems with spatial processing and way-finding (Zeisel, 2006).

The way we experience our environments through our senses is complex and the impacts on our behaviour, health and performance are profound. These responses are particularly hard to predict in the face of interacting influences. Here, humans must make balancing calculations in their brains and this is the focus of the next section.

MEDIATING NEUROSCIENCE PROCESSES

To better understand the relationship between human sense experiences and their powerful effects on human functioning, we can turn to evidence from neuroscience for clues as to the mediation performed through brain functioning. The complexity evident is rooted in the fact that individuals, in practice, experience spaces holistically and interactively. At a base level this is confounded by the cognitive limits of humans, so that perception becomes an 'ill-posed question', in which the brain endeavours to represent reality probabilistically, as best it can using Gestalt grouping rules (Wolfe et al., 2006) correcting the stimuli into usable experience, called 'percepts' (Eberhard, 2007). These perceptions are intricately linked to memory, which relies on a type of matching and recognition of sensory information circuits (p106). Eberhard (2007) describes how our individual reactions to particular spaces, such as a sunny room, draw from these often unconscious memories (p45). He argues that when we experience a new sensation, such as when a child visits a hospital for the first time, *all* the senses will be at work trying to associate the new sensation with the memory cluster, the designer can then work to provide spaces that can be associated with a more pleasant experience (p71).

Specifically, the issue of layout and the navigation between and within spaces provides a good example of the complex, multidimensional way in which data are used and the resulting consequences. Neuroscience studies reveal that the brain operates using three different, but ideally complementary, systems for way-finding. These are:

- reading and interpreting signs;
- remembering routes as part of habitual behaviour, which can be part of our familiarity and attachment with a place (Quayle and Lieck, 1997);
- tracking landmarks in relation to the body (egocentric) or relative to other landmarks (allocentric), using the brain's own mapping system (Hartley et al., 2003).

For any particular space, individuals bring different background experiences and the design of particular spaces may not send coherent messages across the three mechanisms. The result in everyday experience is that way-finding in some spaces is intuitive, while in others confusion reigns.

Underpinning these processes are attentional mechanisms, that give priority to one sense over another, and also help in the construction of the coherent image (Wolfe et al., 2006, p179; Rolls, 2007, p436). So, the various human senses pick up information from our environment and this is processed in the brain in a variety of ways that lead to behaviour based on a mixture of responses, which can be broadly categorized as reflexes/autonomic, implicit or explicit actions (Rolls, 2007, p413). As will be seen below, the role of *implicit*/unconscious responses is particularly interesting in the context of the multisensory experience of spaces, as they subtly influence our explicit thought processes, but also because these effects are themselves powerful, albeit often overlooked.

The sequential process from sense input to response clarifies how all these competing influences interact and how the human brain seeks to make optimal judgements between alternatives. Rolls argues that human behaviour is ultimately motivated by 'primary reinforcers', drawn from our external experience, that are related to survival needs, such as: for clean unputrified air, bounded temperature, the absence of natural dangers, light, shelter, reasonable stimulation and food hoards (Rolls, 2007, pp18–19). This sensory information about the world is collected as raw data that then enters the orbitofrontal cortex of our brain where the value of the environmental stimulus is assessed. This appears to happen by a pattern-matching process (p148) against alternative strings of neuronal associations that are built up and progressively updated. This individual learning process links the elements of situations observed to the built-in primary reinforcers, so giving previously neutral inputs reward value as 'secondary reinforcers' (pp62–67), for example, the sight of food rather than its taste. This reward calculation then feeds forward to the amygdala where individuals hold a sense of the correlation between the prospective actions and the potential rewards.

From here, the information feeds forward to the basal ganglia where inputs from various parts of the brain calling for action are weighed. These result in signals to motor regions and thus behaviour. The explicit system, rooted in the advanced language capacity of the human brain, enables implicit actions to be deferred for reasons connected to longer-term plans (Rolls, 2007, p422). Thus, when experiencing spaces, we will receive a range of sensory inputs that will create an implicit or unconscious response that may or may not be in line with our explicit reaction.

It seems that the implicit response alone does not automatically create behaviour in humans. Although some primary goals may be specified in our genetic material to optimize our behaviour for survival and reproduction, the actions to achieve these goals are not specified, thus allowing for lifetime learning and flexibility (p426). However, the implicit responses, represented in a range of relatively few emotional states or moods, do have an important impact by providing quite weak 'back projections', so influencing the cognitive evaluation of what is experienced or remembered. Thus, in situations where rapid responses are needed or there are too many factors to account for using the explicit system, then the balance may shift more to the implicit system to guide our response (Rolls, 2007, pp198, 415). Furthermore, it would seem that moods are related in our memories to *where* events happened and so the connection between experiences and spaces is an important element of our mood and its impact on our explicit functioning (pp196–197).

DESIGN IMPLICATIONS

The above discussion gives some indication of the range and depth of the research evidence on human sense perception, impacts and the underlying cognitive calculations involved. Building on this and to support application in practice, it is proposed that three design themes can be seen to emerge:

- the role of naturalness;
- the opportunity for individualization;
- appropriate levels of stimulation.

The rationale for the choice of these themes is summarized below.

First, as our emotional systems have evolved over the millennia in response to our natural environment, it does not seem unreasonable to suggest that our comfort is likely to be rooted in key dimensions of 'naturalness' that should, therefore, infuse the design process. The stress here is, of course, on the *positive* aspects of naturalness, such as clean air. At the other extreme, it is known that supernormal stimuli, such as the noise from man-made artefacts, for example cars and guns, can produce super-strong emotions because the stimuli are much more intense (unnatural) than those in which our present emotional systems evolved and that the subsequent responses are not necessarily adaptive (Rolls, 2007, p450).

For schools, significant evidence of positive impacts deriving from aspects of naturalness have been given above, especially around daylighting and planting. For healthcare, planting has been shown to aid recovery of the capacity to focus attention (Kaplan, 1995) and can be contrasted with performance in attentional tests in urban settings (Hartig et al., 2003).

Second, the brain functioning described in the section above highlights the personal way in which individuals build connections between primary reinforcers and complex representations of secondary reinforcers. Taken together with the situated nature of memory, these personal-value profiles lead to highly individual responses to space. This provides a sound basis to raise the potential importance of 'individualization' as an additional, key, underlying design principle. This appears to play out in two ways: particularization and personalization. Particularization concerns accommodating the functional needs of very specific types of users, for example, learning and way-finding in the context of age and physical requirements (Zeisel, 2006). Personalization concerns an individual's preferences resulting from their personal life experiences of spaces. These, of course, will vary greatly from person to person, but the desire is evident in the way people seek to individualize spaces.

Third, lying behind the detail of design elements for general and particular needs, there is also a recurrent theme around the general level of stimulation that is appropriate for given situations. In broad terms this may vary from buildings designed for relaxation, such as homes, to those designed to stimulate, such as theatres, but also variation will be appropriate within buildings. So, in a school, classrooms may need a different approach from assembly areas. More specifically still, focusing on colour, Mahnke (1996) proposes colour palettes for school classrooms that vary every three years to gradually reduce the level of stimulation and increasingly engender concentration as the pupils get older (pp183–184). Thus, a link can be seen here with the issue of individualization, stressing the holistic nature of design solutions. In the context of judging design competitions, Nasar (1999, pp77–85) reinforces the central importance of the level of stimulation produced. Drawing from an extensive literature review, he suggests that combinations of pleasantness (or unpleasantness) and different levels of arousal yield either excitement (or boredom) or relaxation (or distress).

Having set out some of the themes and features that, it is argued, should inform design, it is encouraging to see how these have been operationalized as design parameters in a specific environment with measured impacts. Focusing on the treatment of Alzheimer's patients, Zeisel et al. (2003) have studied the impacts on the well-being of such patients in a range of holistically designed care environments in the US and found clear clinical evidence of improvements in aggression, depression and withdrawal, when compared with other facilities. The successful designs exhibited the set of practical and coherent design features summarized in Table 1.

It can be seen that the themes of (positive) naturalness, individualization and appropriate (low in some places – higher in others) levels of stimulation pervade this design toolkit. It is also evident that complex practical issues are addressed alongside compounding psychological and sociological issues associated with spaces, such as status, control and social belonging (Vischer, 2005). Although, or perhaps because, this example is centred on a particularly vulnerable group, it can be argued that the needs addressed represent a raw exposition of universal human needs.

TABLE 1 Designing for Alzheimer's patients linked to three themes

Feature	Description	Theme(s)
Exit control doors	These are designed to blend into the setting and have coded pushpads to limit residents' access to unsafe areas outside the residence without upsetting them and creating catastrophic reactions	Stimulation
Walking paths	Visually engaging paths with easily identifiable destinations transform aimless wandering and pacing into purposeful walking, thus encouraging residents to move around the residence safely and independently	Stimulation Individualization
Individual privacy	Providing residents with both privacy and the opportunity to be surrounded by familiar furniture, décor, and treasured objects aids them in maintaining a sense of self and improves their recollection and memory	Individualization
Common spaces	Common areas designed to accommodate residential elements and spatial difference – with special attention given to kitchen, living room and activity spaces – provide residents with the cues they need to behave appropriately	Stimulation
Outdoor freedom	Residents' access to safe and supportive healing gardens provides them with cues to time of day and seasons which reduces disorientation and sun-downing as well as comprehensible stimulation and a healing relationship to light, fresh outdoor air and the natural world	Naturalness Stimulation
Residential scale	All rooms and furnishings as well as programmes are designed to reflect a residential setting – to feel 'homey' – reinforcing hard-wired brain elements that reduce anxiety and aggression	Stimulation
Autonomy support	Both environment and programmes encourage residents to use their remaining abilities to carry out daily routines and support them in doing so	Individualization
Sensory stimulation	Sounds, sights and smells are managed so sensory stimulation is familiar and meaningful, over-stimulation is avoided, and total reliance on often-damaged verbal skills is avoided	Stimulation Naturalness

CONCLUSIONS

The early sections of this article illustrated the complex and dynamic ways in which humans receive information about their surroundings through their senses. It was also shown that these multidimensional inputs can have profound, but fragile and interactive effects on human health, mood and performance. Some basic neuroscience theories, about the way the human brain makes calculations to link perceptions to actions, were then used to cast light on a strategic framing of these impacts. This led to the proposition that design that aims to make the most of users' sensory response to spaces should take into account the issues of naturalness, individualization and level of stimulation.

Core to this article is the view that an approach that focuses on the user's sensory perception of spaces opens up a new opportunity to optimize designs around user outcomes. This is not instead of the usual aesthetic aspirations of designers, but alongside this endeavour. This is an argument for an iterative 'inside-out-inside' design process, where the spaces making up the building/area are designed to meet the human needs of those pursuing activities in each space, then the building as a whole is compiled, then the functionality of each space is checked again, and so on. Of course this calls for a design effort that accommodates more information inputs and as such it is a significant design challenge. But the benefits that could flow are significant, for example: schools in which pupils' well-being is improved and where they achieve enhanced academic results; hospitals in which patients need less pain relief and get better faster; offices in which workers are more efficient and productive; and homes and urban areas in which people can live more contently.

As this article indicates, there seems to be tremendous headroom for excellence beyond mere satisficing, that is, to provide safe, comfortable, sustainable and *stimulating* environments as called for in the European Construction Technology Platform Strategic Research Agenda (ECTP, 2005).

This article suggests that the pursuit of optimal built spaces for human use can productively use insights from neuroscience to gain a greater understanding of human responses in complex sensory situations. A wide range of factors appears to be important, such as: the type of stimulus involved, its intensity or quality and factors such as the different reinforcement contingencies and the emotions associated with them. Such complexity reveals the difficulty facing laboratory work in this area. However, greater understanding of the relationship between the various stimuli and the subsequent responses could be gained, linking findings from laboratory work regarding light, colour, etc. with findings from case studies/ experimental buildings involving different uses, such as housing, offices, etc. so that triangulation between the different results can lead to guiding conceptual and virtual models (Barrett and Barrett, 2003).

The examples brought together here highlight that finding optimal solutions is not a simple search for the answer. It is, rather, a subtle process of addressing multiple aspects, linking together the specialist knowledge that is available and moving towards a better understanding of the issues we need to address for specific users. This will help to create an informed context within which robust, multifaceted design solutions can more confidently be derived. If successful, this will lead to the creation of spaces that provide people with sensory environments that help them reach, or sustain, their fullest possible potential. The three themes of naturalness, individualization and level of stimulation have been suggested as productive foci to drive this work forward through a rich programme of multidisciplinary research.

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